PB85-165769

Radionuclides: Background Information Document for Final Rules. Volume 2

(U.S.) Office of Radiation Programs
Washington, DC

Oct 84

U.S. Department of Commerce
National Technical Information Service
NTIS

PB85-165769

United States
Environmental Protection
Agency

Office of
Radiation Programs
Washington, D.C. 20460

EPA 520/1-84-022-2
October 1984

Radiation

EPA

Radionuclides

Background Information Document For Final Rules

Volume II

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA 520/1-84-022-2

2.

3. RECIPIENT'S ACCESSION NO.
PB85 165769/AS

4. TITLE AND SUBTITLE
Background Information Document (Volume II)
(Integrated Risk Assessment)
Final Rules for Radionuclides

5. REPORT DATE
October 22, 1984

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Environmental Protection Agency
Office of Radiation Programs
Washington, D.C. 20460

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS

13. TYPE OF REPORT AND PERIOD COVERED

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This report serves as a background information document in support of the Environmental Protection Agency's final rules for sources of emissions of radionuclides pursuant to Section 112 of the Clean Air Act.

This report presents an analysis of the public health impact caused by radionuclides emitted into the air from facilities that are the subject of this rulemaking. These facilities are examined as six major source categories: (1) Department of Energy (DOE) facilities, (2) Nuclear Regulatory Commission licensed facilities and non-DOE Federal facilities, (3) coal-fired utility and industrial boilers, (4) uranium mines, (5) phosphate industry facilities, and (6) mineral extraction industry facilities.

For each source category, we present the following information: (1) a general description of the source category, (2) a brief description of the processes that lead to the emissions of radionuclides into air, (3) a summary of emissions data, and (4) estimates of the radiation doses and health risks to both individuals and populations.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Clean Air Act Radionuclides Radon DOE Facilities (Department of Energy) Nuclear Regulatory Commission licensed facilities Uranium mines Phosphate Industry		

18. DISTRIBUTION STATEMENT
Unlimited

19. SECURITY CLASS *(This Report)*
Unclassified

20. SECURITY CLASS *(This page)*
Unclassified

21. NO. OF PAGES
474

22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

i

EPA 520/1-84-022-2

40 CFR Part 61
National Emission Standards
for Hazardous Air Pollutants

BACKGROUND INFORMATION DOCUMENT

(INTEGRATED RISK ASSESSMENT)

FINAL RULES FOR RADIONUCLIDES

VOLUME II

October 22, 1984

Office of Radiation Programs
U.S. Environmental Protection Agency
Washington, D.C. 20460

CONTENTS

Page

1. INTRODUCTION 1-1

2. DEPARTMENT OF ENERGY FACILITIES

2.0 Introduction and Summary 2.0-1
References 2.0-9
2.1 Argonne National Laboratory 2.1-1
2.2 Brookhaven National Laboratory 2.2-1
2.3 Feed Materials Production Center 2.3-1
2.4 Fermi National Accelerator Laboratory 2.4-1

2.5 Hanford Reservation 2.5-1
2.6 Idaho National Engineering Laboratory 2.6-1
2.7 Lawrence Livermore National Laboratory 2.7-1
2.8 Los Alamos National Laboratory 2.8-1
2.9 Oak Ridge Reservation 2.9-1

2.10 Paducah Gaseous Diffusion Plant 2.10-1
2.11 Portsmouth Gaseous Diffusion Plant 2.11-1
2.12 Rocky Flats Plant 2.12-1
2.13 Savannah River Plant 2.13-1
2.14 Ames Laboratory 2.14-1

2.15 Bettis Atomic Power Laboratory 2.15-1
2.16 Knolls Atomic Power Laboratory 2.16-1
2.17 Lawrence Berkeley Laboratory 2.17-1
2.18 Mound Facility 2.18-1
2.19 Nevada Test Site 2.19-1

2.20 Pantex Plant 2.20-1
2.21 Pinellas Plant 2.21-1
2.22 Rockwell International Corporation 2.22-1
2.23 Sandia National Laboratories 2.23-1
2.24 Stanford Linear Accelerator Center 2.24-1

2.25 Reactive Metals, Inc. 2.25-1
2.26 Worldwide Impact of Selected Radionuclides 2.26-1
2.27 Future operations at DOE Facilities 2.27-1
2.27(A) Resumption of Operations at the PUREX Plant 2.27-1
2.27(B) Resumption of L-Reactor Operations at the Savannah River Plant 2.27-3

CONTENTS (Continued)

Page

3. NRC-LICENSED FACILITIES AND NON-DOE FEDERAL FACILITIES

3.1 Research and Test Reactors 3.1-1
3.2 Accelerators 3.2-1
3.3 Radiopharmaceutical Industry 3.3-1
3.4 Radiation Source Manufacturers 3.4-1
3.5 Other NRC Licensees 3.5-1
3.6 Department of Defense Facilities 3.6-1
3.6A Armed Forces Radiobiology Research Institute 3.6A-1
3.6B U.S. Army Facilities 3.6B-1
3.6C U.S. Navy Facilities 3.6C-1

4. COAL-FIRED UTILITY AND INDUSTRIAL BOILERS 4.0-1

4.1 Utility Boilers 4.1-1
4.2 Industrial Boilers 4.2-1

5. URANIUM MINES 5-1

6. PHOSPHATE INDUSTRY FACILITIES

6.1 Phosphate Rock Processing Plants 6.1-1
6.2 Wet Process Fertilizer Plants 6.2-1
6.3 Elemental Phosphorus Plants 6.3-1

7. MINERAL EXTRACTION INDUSTRY FACILITIES

Metal Mines, Mills, and Smelters
7.1 Aluminum Industry 7.1-1
7.2 Copper Industry 7.2-1
7.3 Zinc Industry 7.3-1
7.4 Lead Industry 7.4-1

APPENDICES

A. ASSESSMENT METHODOLOGY A-1

B. RADIONUCLIDE EMISSIONS TO AIR FROM FORMER MANHATTAN ENGINEERING DISTRICT AND ATOMIC ENERGY COMMISSION SITES (FUSRAP) B-1

C. RADON EMISSIONS FROM DEPARTMENT OF ENERGY- AND NUCLEAR REGULATORY COMMISSION-LICENSED FACILITIES C-1

D. DEPARTMENT OF ENERGY GOCO FACILITIES D-1

Chapter 1: INTRODUCTION

The purpose of this report is to serve as a background information document in support of the Environmental Protection Agency's (EPA) final rules for sources of emissions of radionuclides pursuant to Section 112 of the Clean Air Act.

This report presents an analysis of the public health impact caused by radionuclides emitted into the air from facilities that are the subject of this rulemaking.

These facilities are examined as six major source categories:

(1) Department of Energy (DOE) facilities

(2) Nuclear Regulatory Commission (NRC) licensed(1) and non-DOE Federal facilities

(3) Coal-fired utility and industrial boilers

(4) Uranium mines

(5) Phosphate industry facilities

(6) Mineral extraction industry facilities

For each source category, we present the following information:

(1) A general description of the source category

(2) A brief description of the processes that lead to the emissions of radionuclides into air

---

(1)Sources are licensed by the Nuclear Regulatory Commission (NRC) or States that have entered into an agreement with the NRC whereby certain regulatory authority is relinquished by the NRC and assumed by the States pursuant to Section 274 of the Atomic Energy Act of 1954, as amended.

(3) A summary of emissions data

(4) Estimates of the radiation doses and health risks to both individuals and populations

Emissions Data

Insofar as possible, measured radionuclide emission data were used to estimate health impacts. In the absence of measured data, estimates were used that were based on calculated or extrapolated values. The data for DOE facilities were obtained from DOE's Effluent Information System for the calendar year 1981 (DOE81); the data for NRC-licensed facilities were obtained from NRC annual effluent reports; and the data for the other categories, such as coal-fired utility and industrial boilers, uranium and nonuranium mines, and the various extraction industries, were usually obtained from special reports prepared under contract with the EPA. Radon emissions from DOE- and NRC-licensed facilities are considered separately in Appendix C of this volume.

Health Impact Assessment

The public health assessment includes estimates of the following radiation exposures and health risks (see Chapter 8, Volume I, for more detail):

(1) Dose-equivalent rates to the individuals at highest risk (nearby individuals)

(2) Collective dose-equivalent rates to population groups

(3) Lifetime risks to nearby individuals in the exposed population

(4) The number of fatal cancers caused in the exposed population per year of facility operation

Assessment Methodology

DOE facilities were analyzed individually on a site-by-site basis. Facilities in all of the other categories were grouped together into source categories on the basis of similarity of activities or operations and analyzed by defining a reference facility that represents the source category. Doses were calculated using the AIRDOS-EPA/DARTAB computer model developed by Oak Ridge National Laboratory under contract to the EPA. These computations are based upon current information on transport, uptake, and metabolic behavior of the various radionuclides and are described in detail in two EPA reports (EPA79, Be81). Appendix A of this volume contains a summary of the parameters used for the AIRDOS-EPA calculations.

Information on emission control technology for facilities in this report is published in documents that are available in Docket A-79-11, Central Docket Section, Gallery One, West Tower Lobby, EPA, 401 M Street, S.W., Washington, D.C. 20460.

Nearby Individuals

Dose-equivalent rates, radon concentrations, and radon decay product exposures are presented for "nearby individuals." To select the location for the nearby individuals, the lifetime risk for an individual at offsite locations (at or beyond the perimeter of the restricted area for each DOE facility) was calculated. Then, the location providing the highest lifetime risk was selected and used for assessing both the dose and risk for nearby individuals.

The dose equivalents presented for nearby individuals are 70-year committed dose equivalents. This is also the dose-equivalent rate in the 70th year following the start of exposure.

Radon decay product exposures presented for nearby individuals are the radon-222 decay product levels to which an individual would be exposed assuming 70-percent equilibrium (i.e., 100 pCi/L radon-222 = 0.7 WL), unless otherwise indicated.

Regional Population

The term regional population refers to the population living within a radius of 80 kilometers of a source. For a few source categories, exposures are presented for the population of the United States or the World, and these cases are specifically identified in the appropriate tables.

Collective dose-equivalent rates are expressed in units of person-rem/year and are the sum of the dose-equivalent rates for all individuals considered in assessing releases from a source. Similarly, collective radon decay product exposure rates are expressed in units of person-working-levels. Further details of these calculations are contained in Appendix A.

Lifetime Risk to Nearby Individuals and Number of Fatal Cancers

The lifetime risk to nearby individuals is the probability of fatal cancer to an individual from a lifetime of exposure (70 years on the average) to the concentrations of radionuclides estimated for that individual.

The number of fatal cancers per year of operation is that potential number of cancers in the population from one year's release of radionuclides from the facility. These cancers are expected to occur many years after the year in which the releases take place.

Numeric Notation and Units

Throughout this report, numeric values are frequently expressed in a modified scientific format. For example, 0.00123, which is equal to 1.23×10^{-3}, may be expressed as 1.23E-3; 3210, which is equal to 3.21×10^{3}, may be expressed as 3.21E+3.

Metric system units have been used for reporting data, except in a few instances where referenced data are presented in their original customary units.

REFERENCES

Be81	Begovich C. L., Eckerman K. F., Schlatter E. C., Ohr S. Y. and R. O. Chester, 1981, DARTAB: A Program to Combine Airborne Radionuclide Environmental Exposure Data with Dosimetric and Health Effects Data to Generate Tabulation of Predicted Impacts. ORNL/5692, Oak Ridge National Laboratory, Tennessee, August 1981.
DOE81	Department of Energy, Effluent Information System (EIS), Calendar year 1981, DOE, Washington, D.C.
EPA77	Environmental Protection Agency, Radiological Quality of the Environment in the United States, EPA 520/1-77-009, Office of Radiation Programs, Washington, D.C., 1977.
EPA79	Environmental Protection Agency, AIRDOS-EPA, A Computerized Methodology for Estimating Environmental Concentrations and Dose to Man from Airborne Releases of Radionuclides, EPA 520/1-79-009, December 1979.

Chapter 2: DEPARTMENT OF ENERGY FACILITIES

2.0 Introduction and Summary

The U.S. Department of Energy (DOE) operates diverse energy and national defense programs involving research, development, and production at a large number of facilities located throughout the United States. These facilities are owned (or leased) by the Federal government and operated by contractors (so-called "GOCO" facilities--Government Owned, Contractor Operated). DOE is granted authority in the Atomic Energy Act of 1954* "to protect the public health and safety from the operation of these facilities, including the emission of radionuclides." This authority is implemented by contractual agreements between DOE and its contractors. This obligates the contractor to comply with all applicable health and safety regulations and requirements of the Department of Energy.

As of 1980, there were 78 facilities in 24 states which were subject to DOE health and safety requirements (see Appendix D). This report examines 25 of these facilities, selected on the basis of having the most significant emissions as listed in the DOE Effluent Information System.** Each of the 25 sites is described in terms of its location, primary mission, major facilities that emit radionuclides, and existing effluent control systems. The information in these descriptions is taken from the annual environmental monitoring reports prepared for each site. This information was supplemented, when necessary, with information from environmental impact statements. Airborne release data for all sites were obtained from the Department of Energy's Effluent Information System and verified against the airborne effluent data in the environmental monitoring reports. All references are presented at the end of this section.

The worldwide impact of these facilities due to the emissions of tritium, carbon-14, krypton-85, and iodine-129 is also assessed. Finally, the impacts of planned future operations at DOE facilities are estimated.

---

*Section 161 of Public Law 83-703.

**Battelle-Columbus and Shippingport Atomic Power Station, which were included the draft report, have been eliminated because they are no longer DOE GOCO facilities.

Existing Emission Standards

DOE health and safety standards are contained in DOE Order 5480.1. The requirements governing airborne releases of radionuclides to the environment are expressed as concentration limits in air at the site boundary. These concentrations can be related to emissions by correcting for atmospheric dilution. A concentration limit, which is established for each radionuclide by DOE, is the concentration of radioactivity in air that causes a dose equivalent to the whole body, gonads, or bone marrow of 500 mrem per year, or 1500 mrem per year to any other organ. In addition, DOE requires that exposures to the public be limited to as small a fraction of the respective annual dose limits as is reasonably achievable.

Summary

The radiation doses and risks of fatal cancers to individuals and populations around Department of Energy facilities were estimated using the methods discussed in Volume I. These estimates are summarized in Tables 2-A through 2-D. More detailed information, including a general description of the facility, a summary of the processes causing the emissions, estimates of the amount of emissions, and more detailed estimates of dose and risk are found in the respective sections of this chapter.

Table 2-A. Summary of dose rates and risks to nearby individuals for facilities with the largest emissions

	Principal emissions		Nearby individuals		
Facility	Radionuclide	Quantity (Ci/y)	Principal organ	Dose rate (mrem/y)	Risk(a) (Units of 10^{-6})
Argonne National Laboratory	Ar-41	0.4	Pulmonary	<0.1	0.0006 (0.0002)
	Kr-85	6.7	Bone(b)	<0.1	
			Breast	<0.1	
			Red marrow	<0.1	
Brookhaven National Laboratory	H-3	660	Pulmonary	0.4	8 (3)
	O-15	36,000	Bone(b)	0.6	
	Ar-41	170	Breast	0.5	
	Xe-127	2.3	Red marrow	0.5	
Feed Materials Production Center	U-234	0.11	Pulmonary	88(c)	100 (100)
	U-238	0.11	Bone(b)	26	
			Red Marrow	1.8	
			Kidneys	12	
Fermi National Accelerator Laboratory	H-3	0.42	Bone(b)	0.7	10 (4)
	C-11	1500	Breast	0.6	
			Red marrow	0.7	

See footnotes at end of table.

Table 2-A. Summary of dose rates and risks to nearby individuals for facilities with the largest emissions (Continued)

	Principal emissions		Nearby individuals			
Facility	Radionuclide	Quantity (Ci/y)	Principal organ	Dose rate (mrem/y)	Risk(a) (Units of 10^{-6})	
Hanford Reservation						
100 Area	H-3	18	Pulmonary	2.2	40	(20)
	Ar-41	65,000	Bone(b)	2.4		
	Kr-88	540	Breast	2.2		
	Cs-138	11,000	Red marrow	2.2		
200 Area	Cs-137	0.05	Red marrow	< 0.1	0.2	(0.1)
	Pu-239	0.0004	Pulmonary	< 0.1		
300-400 Areas	Kr-88	450	Pulmonary	1.4	30	(10)
			Bone(b)	1.5		
			Pancreas	1.4		
Idaho National Engineering Laboratory	H-3	400	Pulmonary	< 0.1	0.5	(0.2)
	Ar-41	2,500	Bone(b)	< 0.1		
	Kr-85	59,000	Thyroid	0.12		
	I-131	0.055	Breast	< 0.1		
			Red marrow	< 0.1		
Lawrence Livermore National Laboratory	H-3	2,600	Red marrow	1.3	30	(10)
	N-13	170	Kidneys	1.3		
	O-15	170	Intestine wall	1.6		
Los Alamos National Laboratory (12 Technical Areas)	H-3	1,100	Bone(b)	11	200	(60)
	C-11	130,000	Breast	9		
	N-13	25,000	Red marrow	11		
	O-15	200,000				
	Ar-41	1,400				
Technical Area 33	H-3	6,100	Bone(b)	0.5	10	(5)
			Breast	0.7		
			Red marrow	0.7		
1983 Emissions TA-33	-	-	Whole body	34	800	(200)
Oak Ridge Reservation	H-3	11,000	Pulmonary	50(d)	100	(100)
	Kr-85	6,600	Bone(b)	7.6		
	I-131	0.6	Thyroid	9.3		
	Xe-133	32,000	Kidneys	5.4		
	U-234	0.12				

See footnotes at end of table.

Table 2-A. Summary of dose rates and risks to nearby individuals for facilities with the largest emissions (Continued)

Facility	Principal emissions		Nearby individuals		
	Radionuclide	Quantity (Ci/y)	Principal organ	Dose rate (mrem/y)	Risk(a) (Units of 10^{-6})
Paducah Gaseous Diffusion Plant	Tc-99	0.006	Pulmonary	4.7(e)	10 (10)
	U-234	0.01	Bone(b)	7.1	
	U-238	0.04	Thyroid	0.2	
			Kidneys	3.6	
Portsmouth Gaseous Diffusion Plant	Tc-99	0.1	Pulmonary	6.9(e)	20 (20)
	Th-234	0.06	Bone(b)	11	
	U-234	0.09	Thyroid	2.0	
			Kidneys	5.1	
Reactive Metals, Inc.	U-234/5/8	0.00048	Pulmonary	52	80 (80)
			Bone(b)	0.3	
			Kidneys	0.1	
			Intestine wall	0.1	
Rocky Flats Plant	H-3	0.43	Pulmonary	<0.1	0.02 (0.02)
	U-234/5/8	0.00003	Bone(b)	<0.1	
	Pu-239/40	0.000008	Red marrow	<0.1	
Savannah River Plant	H-3	350,000	Bone(b)	2.3	40 (20)
	Ar-41	62,000	Thyroid	4.9	
	Kr-85	840,000	Pulmonary	2.2	
	Kr-88	1,500			
	Xe-133	3,900			
	I-131	0.05			
	I-129	0.16			

(a) Off-site location at point of highest dose equivalent. The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

(b) Endosteal cells.

(c) Lung clearance class for uranium: one-third D, one-third W, one-third Y.

(d) Lung clearance class for uranium: all uranium-238 and one-half uranium-234, Y; one-half uranium-234, W.

(e) Lung clearance class for uranium: all W.

Table 2-B. Summary of dose rates and risks to the regional population for facilities with largest emissions

	Principal emissions		Regional population		
Facility	Radionuclide	Quantity (Ci/y)	Principal organ	Dose rate (pers-rem/y)	Fatal cancers/year of operation(a)
Argonne National Laboratory	Ar-41	0.4	Pulmonary	<0.1	<0.001
	Kr-85	6.7	Bone(b)	<0.1	
			Breast	<0.1	
			Red marrow	<0.1	
Brookhaven National Laboratory	H-3	660	Pulmonary	3	<0.001
	O-15	36,000	Bone(b)	3	
	Ar-41	170	Breast	3	
	Xe-127	2	Red marrow	3	
Feed Materials Production Center	U-234	0.11	Pulmonary	440(c)	0.01 (0.01)
	U-238	0.11	Bone(b)	114	
			Red Marrow	8	
			Kidneys	56	
Fermi National Accelerator Laboratory	H-3	0.4	Bone(b)	1.5	<0.001
	C-11	1,500	Breast	1.2	
			Red marrow	1.4	
Hanford Reservation 100 Area, 200 Area, and 300-400 Areas	H-3	18	Pulmonary	11	0.003(<0.001)
	Ar-41	65,000	Bone(b)	13	
	Kr-88	990	Breast	10	
	Cs-138	11,000	Red marrow	11	
Idaho National Engineering Laboratory	H-3	400	Bone(b)	0.3	<0.001
	Ar-41	2,500	Thyroid	5.5	
	Kr-85	59,000	Red marrow	0.2	
	I-131	0.055	Pulmonary	0.2	
			Breast	0.1	
Lawrence Livermore National Laboratory	H-3	2,600	Kidneys	5.8	0.002 (<0.001)
	N-13	170	Intestine wall	7.5	
	O-15	170	Red marrow	5.6	
Los Alamos National Laboratory (12 Technical Areas) and Technical Area 33	H-3	7,200	Bone(b)	63	0.01 (0.005)
	C-11	130,000	Breast	53	
	N-13	25,000	Red marrow	61	
	O-15	200,000			
	Ar-41	1,400			

See footnotes at end of table.

Table 2-B. Summary of dose rates and risks to the regional population for facilities with largest emissions (Continued)

Facility	Principal emissions		Regional population		
	Radionuclide	Quantity (Ci/y)	Principal organ	Dose rate (pers-rem/y)	Fatal cancers/year of operation[a]
Oak Ridge Reservation	H-3	11,000	Pulmonary	212[d]	0.008 (0.006)
	Kr-85	6,600	Bone[b]	22	
	I-131	0.6	Thyroid	15	
	Xe-133	32,000	Kidneys	15	
	U-234	0.12			
Paducah Gaseous Diffusion Plant	Tc-99	0.006	Kidneys	6.7	
	U-234	0.01	Pulmonary	3.4[e]	<0.001
	U-238	0.04	Bone[b]	13	
			Thyroid	0.4	
Portsmouth Gaseous Diffusion Plant	Tc-99	0.1	Pulmonary	11[e]	<0.001
	Th-234	0.06	Bone[b]	35	
	U-234	0.09	Thyroid	7.9	
			Kidneys	17	
Reactive Metals, Inc.	U-234/5/8	0.00048	Pulmonary	19.5	<0.001
			Bone[b]	0.1	
			Kidneys	0.1	
			Intestine wall	0.04	
Rocky Flats	H-3	0.4	Pulmonary	0.1	0.001
	U-234/5/8	0.00003	Bone[b]	0.2	
	Pu-239/240	0.000008	Red marrow	0.01	
Savannah River Plant	H-3	350,000	Pulmonary	103	0.03 (0.01)
	Ar-41	62,000	Thyroid	120	
	Kr-85	840,000			
	Kr-88	1,500			
	Xe-133	3,900			
	I-131	0.05			
	I-129	0.16			

---

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

[b] Endosteal cells.

[c] Lung clearance class for uranium: one-third D, one-third W, one-third Y.

[d] Lung clearance class for uranium: all uranium-238 and one-half uranium-234, Y; one-half uranium-234, W.

[e] Lung clearance class for uranium: all W.

Table 2-C. Summary of individual dose rates and risks to nearby individuals for facilities with small health impact

Facility	Principal organ	Dose rate (mrem/y)	Risk[a] (Units of 10^{-6})	
Ames Laboratory	All organs	0.001	0.02	(0.008)
Bettis Atomic Power Laboratory	Pulmonary	0.004	0.01	(0.008)
Knolls Atomic Power Lab. (Kesselring Site)	Bone[b]	0.08	0.9	(0.4)
Knolls Atomic Power Lab. (Knolls Site)	(c)	(c)	(c)	
Knolls Atomic Power Lab. (Windsor Site)	Bone[b]	0.003	0.04	(0.02)
Lawrence Berkeley Laboratory	Thyroid	1.6	9	(4)
Mound Facility	Bone[b]	0.2	4	(1)
Nevada Test Site	Bone[b]	0.002	0.03	(0.01)
Pantex Plant	Pulmonary	0.005	0.008	(0.007)
Pinellas Plant	Intestine wall	0.3	5	(2)
Rockwell International Corp.	Bone[b]	0.00004	0.00006	(0.00002)
Sandia Laboratories	Bone	0.0009	0.01	(0.006)
Stanford Linear Accelerator Center	Bone[b]	0.006	0.1	(0.04)

(a) Off-site location at point of highest dose equivalent. The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

(b) Endosteal cells.

(c) Kesselring and Knolls sites were assessed as a single combined site.

Table 2-D. Summary of dose rates and risks to the regional population for facilities with small health impact

Facility	Principal organ	Dose rate (person-rem/y)	Fatal cancers/year of operation[a]
Ames Laboratory	Average all organs	0.004	<0.0001
Bettis Atomic Power Laboratory	Average all organs	0.01	<0.0001
Knolls Atomic Power Lab. (Kesselring Site)	Average all organs	0.1	<0.0001
Knolls Atomic Power Lab. (Knolls Site)	(b)	(b)	(b)
Knolls Atomic Power Lab. (Windsor Site)	Average all organs	0.001	<0.0001
Lawrence Berkeley Laboratory	Average all organs	0.7	0.0002 (0.00008)
Mound Facility	Average all organs	8.9	0.003 (0.001)
Nevada Test Site	Average all organs	0.001	<0.0001
Pantex Plant	Average all organs	0.0006	<0.0001
Pinellas Plant	Average all organs	0.9	0.0002 (0.0001)
Rockwell International Corp.	Average all organs	0.0001	<0.0001
Sandia Laboratories	Average all organs	0.003	<0.0001
Stanford Linear Accelerator Center	Bone[c]	0.03	<0.0001

(a)Fatal cancers committed per year of operation of the facility. The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

(b)Kesselring and Knolls sites were assessed as a single combined site.

(c)Endosteal cells.

REFERENCES

Department of Energy, Effluent Information System, Department of Energy, Washington, D.C., 1981.

Argonne National Laboratory

Golchert N. W., Duffy T. L. and Sedlet J., Environmental Monitoring at Argonne National Laboratory--Annual Report for 1981 (ANL-82-12), March 1982.

Moore E. B., Control Technology for Radioactive Emissions to the Atmosphere at U.S. Department of Energy Facilities, PNL-4621, Pacific Northwest Laboratory, October 1984.

Brookhaven National Laboratory

Naidu J. R. and Olmer L. L., Editors, 1981 Environmental Monitoring Report, Brookhaven National Laboratory, Safety and Environmental Protection Division, April 1982.

Energy Research and Development Administration, Environmental Statement, Brookhaven National Laboratory, Upton, New York, ERDA-1540.

Feed Materials Production Center

Fleming D. A., et al., Feed Materials Production Center, Environmental Monitoring Annual Report for 1981, NLCO-1180, NLO, Inc., Cincinnati, Ohio, May 1982.

Fermi National Accelerator Laboratory

Dave M. J. and Charboneau R., Baseline Air Quality Study at Fermilab, ANL Report, ANL/EES-TM-110, 1980.

Universities Research Association, Inc., Environmental Monitoring Report for Fermi National Accelerator Laboratory, Annual Report for CY 1981, FERMILAB 8/22, Universities Research Association, Inc., Batavia, Illinois, May 1982.

U.S. Atomic Energy Commission, Environmental Statement, National Accelerator Laboratory, Batavia, Illinois, WASH-1505, Washington, D.C., 1971.

REFERENCES (Continued)

Hanford Reservation

Energy Research and Development Administration. Final Environmental Impact Statement, Waste Management Operations, Hanford Reservation, Richland, Washington, ERDA-1538, UC-70, Volumes 1 and 2, Washington, D.C., 1975.

Energy Research and Development Administration. Final Environmental Impact Statement, High Performance Fuel Laboratory, Hanford Reservation, Richland, Washington, ERDA-1550, UC-2, 11, Washington, D.C., 1977.

Sula M. J., McCormack W. D., Dirkes R. L., Price K. R., Eddy P. A., Environmental Surveillance at Hanford for CY-81, PNL-4211, May 1982.

Idaho National Enginnering Laboratory

Department of Energy, Environmental Monitoring Program Report for Idaho National Engineering Laboratory Site, IDO-12082 (81), Idaho Operations Office, May 1982.

Energy Research and Development Administration, Final Environmental Impact Statement, Waste Management Operations, Idaho National Engineering Laboratory, ERDA-1536, Washington, D.C., September 1977.

Lawrence Livermore National Laboratory

Auyond M., Griggs K. S., and Buddemeier R. W., Environmental Monitoring at the Lawrence Livermore National Laboratory--1981 Annual Report, UCRL-50027-81, University of California, Livermore, California, March 1982.

Department of Energy, Environmental Impact Statement: Livermore Site, Livermore, California, DOE/EIS-0028, September 1978.

Los Alamos National Laboratory

Environmental Surveillance at Los Alamos During 1981, Los Alamos National Laboratory Report, LA-9349-ENV (UC-41), April 1982.

Department of Energy, Environmental Impact Statement, Los Alamos Scientific Laboratory Site, Los Alamos, New Mexico, DOE/EIS-0018, Washington, D.C., December 1979.

Los Alamos National Laboratory, Environmental Surveillance at Los Alamos During 1983, Los Alamos National Laboratory Report, LA-10100-ENV(UC-41), April 1984.

REFERENCES (Continued)

Oak Ridge Reservation

Union Carbide Corporation, Environmental Monitoring Report, Department of Energy Oak Ridge Facilities, Calendar Year 1981, Y/UB-16, Oak Ridge, Tennessee, May 1982.

Atomic Energy Commission, Environmental Statement: Radioactive Waste Facilities: Oak Ridge National Laboratory, Oak Ridge, Tennessee, WASH-1532, August 1974.

Energy Research and Development Administration, Final Environmental Impact Statement; Management of Intermediate-Level Radioactive Waste: Oak Ridge National Laboratory, Oak Ridge, Tennessee, ERDA-1553, September 1977.

Paducah Gaseous Diffusion Plant

Union Carbide Corporation, Environmental Monitoring Report, Department of Energy, Paducah Gaseous Diffusion Plant, Paducah, Kentucky, May 1982.

Atomic Energy Commission, AEC Gaseous Diffusion Plant Operations, ORO-684, January 1972.

Portsmouth Gaseous Diffusion Plant

Acox T. A., et al., Portsmouth Gaseous Diffusion Plant Environmental Monitoring Report for Calendar Year 1981, Goodyear Atomic Corporation, Piketon, Ohio, April 1982.

U.S. Energy Research and Development Administration, Final Environmental Impact Statement, Portsmouth Gaseous Diffusion Plant Expansion, Piketon, Ohio, ERDA-1555, September 1977.

Rocky Flats Plant

Annual Environmental Monitoring Report, U.S. Department of Energy, Rocky Flats Plant, January through December 1981, RFP-ENV-81, Rockwell International, Energy Systems Group, April 1982.

U.S. Energy Research and Development Administration, Final Environmental Impact Statement, Rocky Flats Plant Site, Golden, Colorado, Vol. 1, ERDA 1545-1, Washington, D.C.

REFERENCES (Continued)

Savannah River Plant

Department of Energy, Environmental Monitoring in the Vicinity of the Savannah River Plant, Annual Report for 1981, DPSPU-82-30-1, E.I. du Pont de Nemours and Company, Aiken, S. C., 1981.

U.S. Energy Research and Development Administration, Final Environmental Impact Statement, Waste Management Operations, Savannah River Plant, Aiken, S. C., ERDA-1537, Washington, D.C., 1977.

Ames Laboratory

Voss M. D., Environmental Monitoring Summary for Ames Laboratory, Calendar Year 1981, IS-4798, Ames Laboratory, Ames, Iowa, April 1982.

Voss M. D., Environmental Monitoring at Ames Laboratory, Calendar Year 1976, IS-4139, Energy Research and Development Administration, Ames Laboratory, Ames, Iowa, 1977.

Bettis Atomic Power Laboratory

Annual Effluent and Environmental Monitoring Report for Calendar Year 1981, Bettis Atomic Power Laboratory, WAPD-RD/E(ESE)-576, April 1982.

Knolls Atomic Power Laboratory

Knolls Atomic Power Laboratory, Environmental Monitoring Report, Calendar Year 1981, KAPL-4148, General Electric Corporation, May 1982.

Lawrence Berkeley Laboratory

Lawrence Berkeley Laboratory, Annual Environmental Monitoring Report of the Lawrence Berkeley Laboratory, 1981, LBL-14553, University of California, Berkeley, California, June 1982.

Mound Facility

Farmer B. M. and Carfagno D. G., Annual Environmental Monitoring Report: Calendar Year 1981, MLM-2930, Monsanto Research Corporation, Mound Facility, Miamisburg, Ohio, April 1982.

U.S. Department of Energy, Final Environmental Impact Statement, Mound Facility, Miamisburg, Ohio, DOE/EIS-0014, Washington, D.C., June 1978.

Nevada Test Site

Black S. C., et al., Offsite Environmental Monitoring Report, Radiation Monitoring Around U.S. Nuclear Test Areas, Calendar Year 1981. Prepared for the U.S. Department of Energy by the EPA Environmental Monitoring Systems Laboratory, EPA-600/4-DOE/DP/00539.

U.S. Energy Research and Development Administration, Final Environmental Statement: Nevada Test Site, Nye County, Nevada, ERDA-1551, September 1977.

Pantex Plant

Environmental Monitoring Report for Pantex Plant Covering 1981, MHSMP-82-14, 1982.

Pinellas Plant

Pinellas Plant Environmental Monitoring Report, 1981, GEPP-EM-654, General Electric Compnay, March 1982.

Rockwell International Corporation

Energy Systems Group, Environmental Monitoring and Facility Effluent Annual Report 1981, ESG-82-21, Rockwell International, Canoga Park, California, July 1982.

Sandia National Laboratories

Energy Research and Development Administration, Environmental Monitoring at Major U.S. Energy Research and Development Administration Contractor Sites, Calendar Year 1976, Volumes 1 & 2, ERDA 77-104/1 & 2, Washington, D.C., 1977

Millard G. C., et al., 1981 Environmental Monitoring Report, Sandia National Laboratories, SAND 82-0833, April 1982.

Stanford Linear Accelerator Center

Annual Environmental Monitoring Report for Stanford Linear Accelerator Center, January-December 1981, SLAC-249, Stanford University, Stanford, California, May 1982.

REFERENCES (Continued)

PUREX Plant

Department of Energy, Draft Environmental Impact Statement, Operation of PUREX and Uranium Oxide Plant Facilities, DOE/EIS-0089D, 1982.

L-Reactor Operation

Department of Energy, Environmental Assessment, L-Reactor Operation, Savannah River Plant, DOE/EA-0195, 1982.

2.1 Argonne National Laboratory; Argonne, Illinois

2.1.1 General Description

Argonne National Laboratory (ANL) occupies the central 6.88 km^2 of a 15.14 km^2 tract in DuPage County, 43 km southwest of downtown Chicago, and 39 km due west of Lake Michigan. It lies in the Des Plaines River Valley, south of Interstate Highway 55 and west of Illinois Highway 83.

Argonne is an energy research and development laboratory with several principal objectives. It conducts a broad program of research in the basic energy and related sciences (physical, chemical, material, nuclear, biomedical, and environmental) and serves as an important engineering center for the study of nuclear and nonnuclear energy sources.

A significant portion of these laboratory studies requires the use of radioactive and chemically-toxic substances.

2.1.2 Description of Facility

The principal nuclear facilities at the Laboratory are a 200 kW light-water cooled and moderated biological research reactor (Janus) fueled with fully-enriched uranium; one critical assembly or zero power reactor (ZPR-9), that is fueled at various times with plutonium, uranium, or a combination of the two; the Argonne Thermal Source Reactor (ATSR), a 10 kW research reactor fueled with enriched uranium; a prototype superconducting heavy ion linear accelerator; a 60-inch cyclotron; several other charged particle accelerators (principally of the Van de Graaff and Dynamitron type); a large fast neutron source (IPNS, Intense Pulsed Neutron Source) in which high energy protons strike a heavy metal target to produce the neutrons; cobalt-60 irradiation sources; chemical and metallurgical plutonium laboratories; and several hot cells and laboratories designed for work with multicurie quantities of the actinide elements. Two major facilities, a 12.5 GeV proton accelerator (ZGS, the Zero Gradient Synchrotron) and a 5 MW heavy water-enriched uranium reactor (CP-5) were not in operation during 1981 and are awaiting decontamination and decommissioning.

2.1.3. Radionuclide Emissions and Existing Control Technology

Airborne emissions from Argonne National Laboratory for 1981 are identified in Table 2.1-1. The emissions for years 1979 through 1981 are summarized in Table 2.1-2. The primary source of tritiated water vapor and argon-41 prior to September 1979 was the CP-5 reactor that was taken out of service at that time. This explains a significant reduction in air emissions as indicated in Table 2.1-1. The only significant releases originated from the JANUS Reactor and the hot cell facility in Building 212. No controls are reported for the JANUS Reactor; however, the exhaust of the hot cell facility employs both HEPA filters and room temperature charcoal traps (Mo83). Calculations of health impact were based on a single release point (stack height of 61 meters).

2.1.4 Health Impact Assessment of Argonne National Laboratory

The estimated annual radiation dose rates from radionuclide emissions in 1981 from Argonne National Laboratory are shown in Table 2.1-3. The nearby individuals are located 900 meters north of the assumed release point, approximately 400 meters beyond the site boundary due to the elevation of the release point (61 meters). The primary exposure pathway is external exposure resulting from argon-41.

Risks of fatal cancer from exposure to the radioactive emissions from this facility are identified in Table 2.1-4. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I.

Table 2.1-1. Radionuclide emissions from Argonne National Laboratory, 1981

Source	Radionuclide	Emissions (Ci)
JANUS Reactor	Argon-41	3.8E-1
Hot cell exhaust	Krypton-85	6.7
	Antimony-125	1.7E-5
Chemical Engineering Laboratory	Tritium	6.9E-7

Table 2.1-2. Radionuclide emissions from Argonne National Laboratory, 1979 to 1981 (Ci/y)

Radionuclide	1979	1980	1981
Antimony-125	8.5E-5	1.5E-4	1.7E-5
Argon-41	7.1E+3	8.1E-1	3.8E-1
Tritium	6.6E+2	9.0	6.9E-7
Krypton-79	1.5E-4	7.1E-4	0
Krypton-85	9.0	5.1	6.7
Krypton-85m	1.4E-5	7.6E-5	0
Xenon-133	3.6E-5	1.4E-5	0
Xenon-135	4.7E-4	6.2E-5	0

Table 2.1-3. Radiation dose rates from radionuclide emissions from Argonne National Laboratory

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Endosteum	3.3E-5	2.6E-3
Red Marrow	3.1E-5	2.5E-3
Breast	3.1E-5	2.4E-3
Pulmonary	3.1E-5	2.5E-3

Table 2.1-4. Fatal cancer risks due to radionuclide emissions from Argonne National Laboratory[a]

Source	Lifetime risk to nearby individuals		Regional population (Fatal cancers/y of operation)	
ANL	6E-10	(2E-10)	6E-7	(3E-7)

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

2.2 Brookhaven National Laboratory; Long Island, New York

2.2.1 General Description

Brookhaven National Laboratory (BNL) is a large scientific research facility located near the center of Long Island approximately 97 kilometers east of New York City. BNL was originally established as a nuclear science research center but has been expanded to include facilities for non-nuclear energy studies and environmental research. Current activities at Brookhaven deal with the transmission, use, and environmental effects of nuclear and nonnuclear energy sources; physical, chemical, and biological radiation studies; and applied nuclear studies, such as those dealing with radioisotopes.

2.2.2 Description of Facility

A wide variety of scientific programs are conducted at Brookhaven. The major facilities at the laboratory include several accelerators, reactors, and groups of laboratories. The facilities that release radioactivity to the atmosphere are described briefly below.

The High-Flux Beam Reactor (HFBR) is a 60-MW(t), fully enriched, heavy-water-moderated, -cooled, and -reflected reactor. It provides intense neutron beams for research. The core is contained in an aluminum vessel and operated at a pressure of 14.1 kg/cm^2. The reactor, its auxiliary equipment, and its experimental facilities are housed in a welded steel hemisphere 54 meters in diameter. The reactor cover gas is helium, contaminated with air, fission products, D_2O decomposition products, D_2O vapor, and tritiated heavy water vapor (DTO).

The Alternating Gradient Synchrotron (AGS) is a 33-GeV proton accelerator used for ultra-high energy particle physics research. Protons originate in a 0.75 MeV Cockcroft-Walton generator, are accelerated by a 200-MeV linear accelerator (linac) and injected into the AGS. The proton beam may be deflected to strike a target or into one of the several experimental areas.

The 200-MeV linac also serves the Brookhaven Linac Isotope Production Facility (BLIP) and the Chemistry Linac Irradiation Facility (CLIF). The BLIP was built to utilize the excess capacity of the linac to produce significant quantities of radionuclides that can be made in no other way. The principal component of the BLIP is a 10-meter deep, 2.4-meter diameter water-filled tank, into the bottom of which the 200-MeV proton beam is directed horizontally. The targets are individually jacketed and lowered to the 20-centimeter diameter irradiation chamber through J-shaped tubes. The CLIF, which is operated in a similar way, provides convenient irradiation of targets with surplus protons from the linac or secondary neutrons generated by a converter beam stop. CLIF targets are shuttled into the beam via a pneumatic target transfer system.

The Tandem Van de Graaff accelerator consists of two electrostatic accelerators capable of independent or tandem use. Maximum achievable particle energy is 30 MeV. Particles ranging from hydrogen (light) to chlorine (heavy) have been accelerated. During accelerator operation, the particle beams are magnetically directed to various targets for study of nuclear and atomic reactions.

The Brookhaven Medical Research Reactor (MRR) is a tank-type, fully enriched, water-cooled and -moderated reactor. It operates intermittently at power levels up to 3 MW (thermal) at a pressure of 246 g/cm^2. It is an integral part of the Medical Research Center and is used for various research programs requiring irradiation facilities.

An intersecting storage ring accelerator, "ISABELLE," is currently under construction and will be operational sometime in the 1980s. ISABELLE will be a colliding beam machine, in which the collision of two proton beams of 400 GeV will make available effective energies up to 800 GeV. The machine will be used to conduct advanced studies in high energy physics.

BNL has several laboratories, one of which is the Hot Laboratory Complex. The Hot Lab originally provided shielded areas for research and development work with large amounts of radioactive material. It includes three remotely operable hot cells, a large radioactive metals hot cell, and several totally sealed systems for use with alpha-emitting materials. Post-irradiation processing of BLIP targets is done in one corner of the building. Liquid wastes generated within the Hot Lab are pumped to storage tanks and evaporated to a slurry. The distillate flows to the sanitary sewer, and the slurry is packaged at the Waste Management Facility and shipped as solid waste for offsite disposal.

Additional programs involving irradiations and/or the use of radionuclides for scientific investigations are carried on at other Laboratory facilities including the Biology Department, the Chemistry Department, and the Department of Energy and Environment.

2.2.3 Radionuclide Emissions

Most of the airborne radioactive effluents at Brookhaven originate from the HFBR, BLIP, and the research Van de Graaff, with lesser contributions from the Chemistry and Medical Research Centers.

Radioactive releases occurred during 1981 from the seven stacks that are identified in Table 2.2-1. The quantities discharged to the atmosphere are listed in Table 2.2-2. Tritium is the most frequently discharged contaminant, although oxygen-15 ($t_{1/2}$ = 122 sec) is discharged in greatest quantity. About 63 percent of the tritium is released from the Van de Graaff stack (S-2). The BLIP stack (S-7) contributes all of the oxygen-15, while the HFBR stack (S-3) contributes 37 percent of the tritium and all xenon-127 and unidentified beta, gamma-ray releases. Thus, only small quantities of radionuclides are released from the other four sources.

Table 2.2-1. The stacks at BNL from which radionuclides were released during 1981

Stack Number	Location	Height (m)
S-1	Chemistry Building-555	17
S-2	Van de Graaff Acc., Building-901	18
S-3	HFBR - Hot Laboratory	98
S-4	Hazardous Waste Management Area	10
S-5	MRC, Building-490	14
S-6	MRR, Building-491	46
S-7	BLIF, Building-931	18

Table 2.2-2. Radionuclide emissions (Ci) from Brookhaven National Laboratory by stack number, 1981

Radionuclide	Stack Number[a]						
	S-1	S-2	S-3	S-4	S-5	S-6	S-7
Tritium	4.3	4.1E+2	2.4E+2	1.8E-1	1.1	6.6E-2	
Beryllium-7				2.6E-3			
Carbon-14				8.1E-4			
Oxygen-15							3.6E+4
Phosphorus-32					1.5E-4		
Sulfur-35				5.7E-3			
Argon-41						1.7E+2	
Iron-59				2.5E-4			
Tin-113				2.6E-4			
Iodine-125				9.9E-4			
Xenon-127			2.3				
Unid. beta, gamma			1.8E-4				

[a] See Table 2.2-1 for stack identification.

The Brookhaven site covers approximately 21.3 square kilometers. However, all airborne radioactive releases from the site, excluding those from the Hazardous Waste Management Area, are located in an area that is only slightly greater than 1 square kilometer. Because only very small quantities of radioactivity are discharged from the 10 m incinerator stack (S-4) in the Hazardous Waste Management Area (See Table 2.2-2), the Brookhaven Facility was modeled with only one airborne radioactive release point: a stack positioned approximately central to the other six effluent stacks (S-1 to S-3 and S-5 to S-7). To be conservative, 18 m was selected as the height of the hypothetical stack representing the point source of airborne discharge. Table 2.2-3 compares the radionuclide emissions for 1979 to 1981.

Table 2.2-3. Radionuclide emissions (Ci/y) from Brookhaven National Laboratory, 1979 to 1981

Radionuclide	1979	1980	1981
Argon-41	3.2E+2	2.6E+2	1.7E+2
Beryllium-7	NR	NR	2.6E-3
Carbon-14	NR	NR	8.1E-4
Iodine-125	NR	NR	9.9E-4
Iron-59	NR	NR	2.5E-4
Oxygen-15	2.8E+4	2.6E+4	3.6E+4
Phosphorus-32	NR	NR	1.5E-4
Sulfur-35	NR	NR	5.7E-3
Tin-113	NR	NR	2.6E-4
Tritium	2.3E+2	5.5E+2	6.6E+2
Unidentified beta + gamma	1.7E-4	7.8E-5	1.8E-4
Xenon-127	1.0	1.6	2.3

NR None reported.

2.2.4 Health Impact Assessment of Brookhaven National Laboratory

The estimated annual radiation doses for this facility are summarized in Table 2.2-4. The assessment was based on all emissions in 1981 being combined into one point source. The nearby individuals are located 1300 meters north-northwest from the hypothetical 18 m stack. The population within the 80 km radius assessment area is about 4.6 million.

The majority of the dose was due to oxygen-15 through the air immersion pathway. The exposure to the regional population was primarily due to tritium and oxygen-15.

The risks of fatal cancer as a result of exposure to the radioactive emissions from this facility are listed in Table 2.2-5. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume 1.

Table 2.2-4. Radiation dose rates from radionuclide emissions from Brookhaven National Laboratory, 1981

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Pulmonary	4.4E-1	3.1
Red marrow	5.4E-1	3.3
Breast	4.7E-1	3.2
Liver	4.1E-1	3.0
Endosteum	5.6E-1	2.9

Table 2.2-5. Fatal cancer risks due to radionuclide emissions from Brookhaven National Laboratory, 1981(a)

Source	Lifetime risk to nearby individuals	Regional population (Fatal cancers/y of operation)
BNL	8E-6 (3E-6)	9E-4 (4E-4)

(a)The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

2.3 Feed Materials Production Center; Fernald, Ohio

2.3.1 General Description

The Feed Materials Production Center (FMPC), operated by NLO, Inc., is located on 425 hectares in southwestern Ohio in Hamilton and Butler counties. The facility is 1.6 kilometers north of Fernald and 32 kilometers northwest of Cincinnati. The population within an 80 kilometer radius of FMPC is 2.6 million.

2.3.2 Description of Facility

The Feed Materials Production Center produces purified uranium metals, uranium rod and tubing extrusions, uranium compounds, and some thorium compounds for use by other Department of Energy (DOE) facilities. Uranium may be natural, depleted, or enriched with respect to uranium-235; the average uranium-235 content is that of natural uranium. Feed stock may be ore concentrates, recycled uranium, or various uranium compounds.

Impure feedstock is dissolved in nitric acid, and the uranium is separated by organic liquid extraction. It is then reconverted to uranyl nitrate, heated to form a trioxide powder, reduced with hydrogen to uranium dioxide, and reacted with anhydrous hydrogen fluoride to produce uranium tetrafluoride. Purified metal is produced by reacting uranium tetrafluoride with metallic magnesium in a refractory-lined vessel, remelted with scrap uranium metal, and cast into ingots. From these ingots, uranium rods and tubing are extruded, cut, machined, and finally sent to other DOE facilities for fabrication into nuclear reactor fuel elements.

The facility periodically purifies small quantities of thorium through production steps similar to those outlined above for uranium. Finished products include thorium metal, thorium nitrate solution, and solid thorium compounds.

There are eight buildings at FMPC for these production activities. The processes associated with each of the eight buildings are as follows:

Plant 1	Material sampling and grinding;
Plant 2	Dry feeds digestion;
Plant 4	Uranium tetrafluoride production and repackaging;
Plant 5	Metal production and slag grinding;
Plant 6	Metal machining;
Plant 8	Dumping and milling;
Plant 9	Metal production, remelting, and machining;
Pilot Plant	Uranium and thorium metal and compound production.

2.3.3 Radionuclide Emissions and Existing Control Technology

Table 2.3-1 summarizes the radionuclide emissions from FMPC in 1981 for each of the eight stacks and an on-site incinerator. Exhausted air from these buildings is passed through scrubbers or cloth type bag filters prior to release to building stacks. Only natural uranium was released during 1981; no thorium was released during the year.

Table 2.3-1. Radionuclide emissions from Feed Materials Production Center, 1981 (Ci/y)

Source	Uranium emissions (Ci/y)	
	Uranium-238	Uranium-234
Plant 1	3.3E-4	3.3E-4
Plant 2	0.	0.
Plant 4	6.26E-2	6.26E-2
Plant 5	4.46E-2	4.46E-2
Plant 6	0.	0.
Plant 8	5.33E-3	5.33E-3
Plant 9	0.	0.
Pilot Plant	0.	0
Incinerator	4.15E-4	4.15E-4
Total	0.113	0.113

2.3.4 Health Impact Assessment of FMPC

For the health impact assessment, all releases were assumed to originate from a single 10-meter stack at the center of the production area. Since only natural uranium was released during 1981, the assumption was made that the release consisted of one-half uranium-234 and one-half uranium-238 in equilibrium with its daughters, thorium-234 and protactinium-234m. Uranium emissions are assumed to be one-third Class Y, one-third Class W, and one-third Class D.

The estimated annual radiation doses from radionuclide emissions from FMPC are shown in Table 2.3-2. The estimates of regional population dose are for a regional population of 2.6 million. The nearby individuals are located 810 m northeast of the release point at the site boundary. The major pathway of exposure is inhalation, and the critical organ is the pulmonary.

The estimated individual lifetime risk and the number of fatal cancers per year of operation are shown in Table 2.3-3. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I.

Table 2.3-2. Radiation dose rates from radionuclide emissions from the Feed Materials Production Center

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Pulmonary	88	436
Endosteum	26	114
Kidney	12	56
Red marrow	1.8	8

Table 2.3-3. Fatal cancer risks due to radionuclide emissions from the Feed Materials Production Center

Source	Lifetime risk to nearby individuals	Regional population (Fatal cancers/y of operation)
FMPC	1E-4	1E-2

2.4 Fermi National Accelerator Laboratory; Batavia, Illinois

2.4.1 General Description

The Fermi National Accelerator Laboratory (FNAL) is located in the Greater Chicago area just east of Batavia, Illinois, on a 27.5 km^2 tract of land. The site is roughly 4.8 km square and is operated for the Department of Energy (DOE) by the University Research Associates, Inc. The facility is composed of three basic elements: the accelerator, experimental areas, and support facilities.

The primary purpose of FNAL is fundamental research in high energy physics. In addition, cancer patients are treated using neutrons released by the interaction of 66 MeV protons from the second stage of the accelerator. A major program is in progress to construct, install, and operate a ring of superconducting magnets. The goal is to produce higher energy protons using less electrical power.

The surrounding area is rapidly changing from farming to residential use. There are many municipalities in the vicinity, resulting in a distinct pattern of high population concentration. Within a 3-km distance from the Laboratory boundaries, Batavia (pop. 12,169), Warrenville (pop. 7,185), and West Chicago (pop. 12,444), are located. The total population within a 80 km radius of FNAL is more than 7.5 million.

2.4.2 Description of Facility

The FNAL is a proton synchrotron with an original design energy of 200 GeV (billion electron volts). As a result of accelerator improvements, protons were accelerated to an energy of 500 GeV in 1976 and operation at 400 GeV is now routine.

The proton beam extracted for high energy physics from the 2-km diameter main accelerator is taken to three different experimental areas on site, the Meson, Neutrino, and Proton Areas. All three areas received proton beams for the first time in 1972. Radioactivity is produced as a result of the interaction of the accelerated protons with matter. The total number of protons accelerated in 1981 was 1.4×10^{19}.

2.4.3 Radionuclide Emissions and Existing Control Technology

Activation of air in measurable concentrations occurs wherever the proton beam or the spray of secondary particles resulting from its interactions with matter passes through the air. Along most proton beam lines (paths of the protons from the accelerator), the protons travel inside evacuated pipes. Thus, activation of air is usually caused by secondary particles.

Radioactive gas, primarily carbon-11, is produced by interaction of secondary particles with air. Monitoring is carried out by detecting the beta particles emitted in the radioactive carbon-11 decay. A release of 1.45 kCi occurred from the labyrinth stack in the Neutrino Area during 1981.

There was also a controlled release of tritium in tritiated water evaporated as a means of disposal for the first time at Fermilab in 1981. The total quantity released to the atmosphere was 420 mCi. The release occurred from the Meson Area.

A debonding oven was placed in operation in 1979. Its purpose is to debond failed magnets by decomposing the epoxy adhesives at high temperatures. Most of these magnets are radioactive. Thirty magnets were debonded in 1981, and the total tritium release was approximately 5 mCi. Table 2.4-1 lists the activity, location, and stack heights of the FNAL airborne releases for 1981. Table 2.4-2 summarizes the airborne releases from 1979 to 1981. The primary control of airborne radioactive emissions is hold-up confinement. The accelerator is designed for high efficiency, so that proton losses are small during acceleration, extraction, and transport to the experimental-area targets.

The accelerator, beam-transport, and target systems are all within well-shielded housings, while the beam travels in evacuated pipes, thus reducing the activation of air.

2.4.4 Health Impact Assessment of Fermi Laboratories

The estimated annual radiation doses resulting from radionuclide emissions in 1981 from the Fermi Laboratories are listed in Table 2.4-3. Nearby individuals are located 1300 meters north of the release location. The predominant exposure pathway is that of air immersion. The dose is primarily (greater than 99 percent) from carbon-11.

Table 2.4-4 lists the estimates of the lifetime risk to nearby individuals and the number of fatal cancers to the regional population from these doses. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I.

Table 2.4-1. Radionuclide emissions from Fermi National Accelerator Laboratory, 1981

Source[a]	Radionuclide	Emissions (Ci)
Neutrino Area	Carbon-11	1.5E+3
Meson Area	Tritium	4.2E-1
Debonding oven	Tritium	5.0E-3

[a] Stack height = 10 meters.

Table 2.4-2. Radionuclide emissions from Fermi National Accelerator Laboratory, 1979 to 1981 (Ci/y)

Radionuclide	1979	1980	1981
Carbon-11	4.0E+3	1.3E+3	1.5E+3
Tritium	2.8E-1	2.4E-1	4.2E-1

Table 2.4-3. Radiation dose rates from radionuclide emissions from Fermi National Accelerator Laboratory, 1981

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Red marrow	6.7E-1	1.4
Endosteum	6.9E-1	1.5
Breast	5.8E-1	1.2

Table 2.4-4. Fatal cancer risks due to radionuclide emissions from Fermi National Accelerator Laboratory, 1981[a]

Source	Lifetime risk to nearby individuals	Regional population (Fatal cancers/y of operation)
FNAL	1E-5 (4E-6)	3E-4 (1E-4)

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

2.5 Hanford Reservation; Richland, Washington

2.5.1. General Description

The Hanford Reservation is a 1,500 square-kilometer site located 270 kilometers southeast of Seattle, 200 kilometers southwest of Spokane, Washington, and 230 kilometers east of Mt. St. Helens. The Columbia River flows through the northern edge of the Hanford site and forms part of its eastern boundary.

Facilities on the Hanford Reservation include the historic reactor facilities for plutonium production along the Columbia River in the 100 Area. The reactor fuel processing and waste management facilities are on a plateau about 11.3 kilometers from the river in the 200 Area. The 300 Area, just north of the city of Richland, contains the reactor fuel manufacturing facilities and research and development laboratories. The Fast Flux Test Facility (FFTF) is located in the 400 Area approximately 8.8 kilometers northwest of the 300 Area, and the Washington Public Power Supply System (WPPSS) power reactor site is about 4.3 kilometers (2.7 miles) north of the 300 Area.

Privately-owned facilities located within the Hanford Reservation boundaries include the WPPSS generating station adjacent to N-Reactor, the WPPSS power reactor site and office buildings, and a radioactive waste burial site. The Exxon fuel fabrication facility is located immediately adjacent to the southern boundary of the Hanford Reservation.

The facilities at the Hanford Reservation are operated for the Department of Energy by four prime contractors. The current contractors and their primary roles are:

- Rockwell International's Rockwell Hanford Operations (RHO): waste management, fuel processing, and all site support facilities

- UNC Nuclear Industries (UNC): N-reactor operation and fuel fabrication

- Battelle's Pacific Northwest Laboratory (PNL): research in biophysics and biomedicine and development of advanced waste management technologies

- Westinghouse Hanford Company (WHC): operation of Hanford Engineering Development Laboratory (HEDL), including advanced reactor development (principally the Liquid Metal Fast Breeder Reactor Program).

2.5.2 Description of Facility

The Hanford Reservation was originally established in 1943 to produce plutonium for nuclear weapons. At one time, nine production reactors were in operation, including eight with once-through cooling. Between December 1964 and January 1971, all eight reactors with once-through cooling were deactivated. N-Reactor, the remaining production reactor in operation, has a closed primary cooling loop. Steam from N-Reactor operation is used to drive turbine generators that produce up to 860 million watts of electrical power in the Washington Public Power Supply System's (WPPSS) Hanford Generating Plant. By the end of 1976, N-Reactor had supplied enough steam to produce nearly 35 billion kilowatt-hours of electrical energy, which was fed to the Bonneville Power Administration grid covering the Pacific Northwest.

Presently, plutonium production has decreased and other programs have been introduced and developed. Current operations include plutonium production and fabrication, management and storage of radioactive wastes, reactor operations and fuel fabrication, energy research and development, and biophysical and biomedical research.

100 Area

The 100 Area is the location of the original nine plutonium production reactors in the northern area of the Hanford site approximately 8 to 10 kilometers from the northern site boundary and adjacent to the Columbia River. The 100 Area is approximately 45 kilometers north-northwest of Richland. Eight of the reactors have been deactivated and placed on standby. Operating facilities in the 100 Area include the N-Reactor and the 1706 Laboratory.

The N-Reactor is operated by UNC and is the only plutonium production reactor still in operation on the Hanford Reservation.

Pacific Northwest Laboratory operates the 1706 Laboratory located in the 100-K Area. The laboratory conducts studies of water quality, filtration, and corrosion in support of N-Reactor operations. Small-scale decontamination studies are also done at the laboratory.

200 Area

The 200 Area is divided into the 200 East Area and the 200 West Area. The 200 East Area is located in the center of the Hanford site, approximately 15 kilometers from the east and west site boundaries and 35 kilometers north-northwest of Richland. Activities conducted in this area include irradiated fuel processing, waste management and storage, and laboratory research. The 200 West Area is adjacent to the 200 East Area. Activities conducted in the area include waste treatment and storage, equipment decontamination, plutonium and uranium processing, and laboratory research.

The PUREX Plant, located in the 200 East Area, is the fuel reprocessing facility at Hanford. Since 1972 the PUREX Plant has been held in standby and is scheduled to resume operation no later than April 1984 and continue through the year 2000. See Section 2.27 for a discussion of the future operations of DOE facilities.

Another facility in the 200 East Area is the Critical Mass Laboratory which is operated by PNL. This laboratory is used for research on the criticality safety of plutonium in its various forms and combinations with other elements. All of the remaining facilities in the 200 East Area are used for waste treatment and storage. Included among these facilities are B-Plant, C-Plant, the AR and CR vaults, and the numerous tank farms.

Major facilities in the 200 West Area include the UO_3 plant, the Z-Plant, and the Redox Plant. Uranyl nitrate hexahydrate solution (UNH) is converted to UO_3 at the UO_3 Plant. The Z-Plant has been used to finish the processing of plutonium separated during the PUREX process. Currently, a capability to complete the processing of plutonium oxide has been added to the PUREX plant; therefore, the Z-Plant will no longer be used for this purpose. The Z-Plant presently reclaims plutonium from scrap. The Redox facility currently houses Laboratories 222-S and 219-S which conduct studies in support of B-Plant operations and waste management processes.

Support facilities in the 200 West Area include the T-Plant, used for equipment repair and decontamination projects; the Plutonium Metallurgy Laboratory, operated by PNL; facility tank farms; the 242T waste evaporator; and the laundry facility.

300 Area

The 300 Area, which is in the southeast corner of the reservation, is the site of most of the laboratory and research facilities at Hanford. This area is 8 kilometers north of Richland and adjacent to the east site boundary. The major facilities are the Hanford Engineering Development Laboratory (HEDL), the fuel fabrication facility, and the Life Sciences Laboratory.

The Hanford Engineering Development Laboratory is the major facility in the 300 Area. It consists of numerous laboratories, testing facilities, and storage areas utilized in support of the Fast Breeder Reactor (FBR) program at Hanford. These facilities are operated by Westinghouse Hanford Company for the Department of Energy.

The fuel fabrication facility is operated by UNI. It is used in the production of fuel pins for the N-Reactor. The Life Sciences Laboratory is operated by PNL; current programs include biophysical and biomedical research. Studies on the inhalation of plutonium which were formerly conducted in the 100 areas were transferred to this facility in 1975. In addition, PNL operates two laboratories that conduct research in advanced waste management techniques and metallurgical techniques. These laboratories are the Metal Fabrication Laboratory and the 3720 Laboratory.

Previous programs at Hanford generated radioactive wastes which were buried in the 300 Area. These areas are not presently in use, and radioactive wastes that are being generated by current programs are shipped to the 200 Areas for processing and disposal. No airborne effluents are released from the buried wastes.

400 Area

The 400 Area is the newest of the operational areas to be developed at Hanford. The area is approximately 9 kilometers northwest of the 300 Area and 5 kilometers from the south and east site boundary. At present, the Fast Flux Test Facility (FFTF) is in operation in the 400 Area and the Fuel Materials Examination Facility (FMEF) is under construction in the 400 Area. When these facilities are both in operation, the 400 Area will be the center for the fast breeder reactor development program at Hanford.

2.5.3 Radionuclide Emissions and Existing Control Technology

The airborne releases at Hanford Reservation are presented in Table 2.5-1. The site is large, covering an area of 1,500 square kilometers. For the purposes of analysis, Hanford is regarded as having three point sources for emissions, each at a height of 1 m above the surface. These are located in the 100 Area, 200 Area, and the combined 300-400 Area. The release point in the 100 Area is 8 kilometers from the northern site boundary at the location of N-reactor. The 200 Area stack is 10 kilometers from the southern site boundary and is located at a point midway between 200 east and 200 west Areas. The 300-400 Area release point is 0.25 kilometers from the southern boundary.

All particulates released from Hanford operations are assumed to be less than 1 micron in size. Airborne effluents from the N-Reactor constitute more than 95 percent of the releases in the 100 Area. Releases from the N-Reactor are passed through HEPA filters and activated charcoal filters, while emissions from the 1706 Laboratory are exhausted through HEPA filters only.

In the 200 Area, residual operations presently occurring at the PUREX Plant account for the majority of the plutonium released in the area. Airborne effluents from all 200 Area release points are passed through acid scrubbers, deentrainers, fiberglass filters, and HEPA filters prior to release. In addition, releases from the PUREX plant are passed through a silver nitrate reactor to remove elemental iodine. Emissions from all waste management functions in the 200 East Area account for the significant release of beta- and gamma-emitting nuclides and one-third of the plutonium emissions.

In the 200 West Area, emissions from the Z-Plant include 70 percent of the area beta-gamma releases. These releases are filtered through either multilayered sand filters or HEPA filters. In addition, 80 percent of the plutonium from the U-Plant (adjacent to the UO_3 Plant) is released untreated. Discharges of plutonium-239 from Z-Plant represent more than 80 percent of the total plutonium released in the area. All of the release points at the Z-Plant are fitted with one, two, or three HEPA filters to control particulate emissions.

In the 300 Area, the fuel fabrication facility is responsible for most of of the natural uranium discharged in the area. All discharges pass through HEPA filtration prior to release.

2.5.4 Health Impact Assessment of the Hanford Site

A separate health risk assessment was performed for each of the three sources considered at this site. Summaries of these analyses are given in Table 2.5-2 and Table 2.5-3. The risk estimates in Table 2.5-3 include estimates which utilize a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I. The size of the regional population differs for each source (266,000 for the 100 Area, 259,000 for the 200 Area, and 199,000 for the 300-400 Area). The nearby individuals for the 100 Area are 7500 m northwest of the source. For the 200 Area, the nearby individuals are 16,000 m south of the release point. The nearby individuals for the 300-400 Area are also south of the facility, at a distance of 2000 meters.

Table 2.5-1. Radionuclide emissions from the Hanford Reservation, 1981

Radionuclides	Emissions (Ci/y)		
	100 Area	200 Area	300-400 Area
Argon-41	6.5E+4		
Arsenic-76	2.3E-2		
Carbon-14	3.2		4.5E-7
Barium-Lanthanum-140	1.1E-1		
Cerium-144	7.9E-2		
Cobalt-58	6.6E-3		
Cobalt-60	1.6E-2		3.3E-7
Cesium-137	8.9E-3	5.0E-2	
Cesium-138	1.1E+4		
Europium-154	1.5E-1		
Europium-155	2.5E-2		
Iron-59	2.7E-3		
Tritium	1.8E+1		
Iodine-131	9.7E-2		3.0E-4
Iodine-132	4.3		
Iodine-133	9.4E-1		
Iodine-135	1.6		
Krypton-85m	2.5E+2		
Krypton-87	2.8E+2		
Krypton-88	5.4E+2		4.5E+2
Manganese-54	2.8E-3		
Manganese-56	4.6E-1		
Sodium-24	1.2E-1		
Plutonium-239	6.4E-5	3.7E-4	2.2E-5
Ruthenium-103	3.3E-3		
Ruthenium-Rhodium-106	4.2E-3		
Strontium-89	1.5E-3		
Strontium-90	4.8E-3	3.1E-3	8.8E-5
Strontium-91	1.8E-1		
Molybdenum-Technetium-99m	2.5E-1		
Uranium-234			7.5E-5
Uranium-238			7.5E-5
Xenon-135	4.6E+2		

Table 2.5-2. Radiation dose rates from radionuclide emissions from the Hanford Reservation, 1981

Organ	Nearby individuals (mrem/y)		
	100 Area	200 Area[a]	300-400 Area
Red marrow	2.2	2.0E-2	1.2
Endosteum	2.4	8.4E-2 (8.3E-2)	1.5
Pulmonary	2.2	2.1E-2	1.4
Pancreas	2.1	9.2E-3	1.4
Breast	2.2	1.1E-2	1.3

Organ	Regional population (person-rem/y)		
	100 Area	200 Area[a]	300-400 Area
Red marrow	6.9	3.8E-1 (3.6E-1)	3.8
Endosteum	8.8	1.1 (1.0)	4.7
Pulmonary	5.9	2.3E-1	4.5
Thyroid	5.8	1.8E-1 (1.6E-1)	4.1
Breast	6.2	2.0E-1 (1.9E-1)	4.0
Pancreas	5.5	2.0E-1 (1.9E-1)	4.3

(a)The dose rates in parentheses are based on NRPB Publication R129; see Chapter 7, Volume I, of this report.

Table 2.5-3. Fatal cancer risks due to radionuclide emissions from the Hanford Reservation, 1981(a)

Source	Lifetime risk to nearby individuals	Regional population (Fatal cancers/y of operation)
100 Area	4E-5 (2E-5)	2E-3 (7E-4)
200 Area	2E-7 (1E-7)	6E-5 (2E-5)
300-400 Area	3E-5 (1E-5)	1E-3 (5E-4)

(a)The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

2.6 Idaho National Engineering Laboratory; Upper Snake River Plain

2.6.1 General Description

The Idaho National Engineering Laboratory (INEL) is a large R&D facility located in southeastern Idaho. INEL was established in 1949 (then called the National Reactor Testing Station) to provide an isolated station where various kinds of nuclear reactors and support facilities could be built and tested. The site encompasses 2,314 square kilometers and is situated 35 kilometers west of Idaho Falls and 37 kilometers northwest of Blackfoot. As of 1981, 52 reactors had been built, 17 of which were still operating or operable.

Current programs at INEL are conducted at various areas of the site and are managed for DOE by four contractors: EG&G Idaho, Inc.; Exxon Nuclear Idaho Company, Inc.; Argonne National Laboratory; and Westinghouse Electric Corporation.

EG&G Idaho, Inc., operates the Power Burst Facility located in the Special Power Excursion Reactor Test Area (SPERT); the Advanced Test Reactor, located in the Test Reactor Area (TRA); the Technical Support Facility (TSF), located in the Test Area North (TAN); and the Loss-of-Fluid Test Facility, located in the Test Area North (TAN). Programs that require the use of these facilities include test irradiation services from the two operating high-flux reactors and light-water-cooled reactor safety testing and research. Exxon Nuclear Idaho Company operates the Idaho Chemical Processing Plant. One of the activities performed here is the recovery of uranium from highly enriched spent fuels. Argonne National Laboratory-West (ANL-W) operates the Experimental Breeder Reactor No. 2 and related support facilities. Westinghouse Electric Corporation operates the Naval Reactor Facility at INEL.

2.6.2 Description of Facility

EG&G Facilities

The Power Burst Facility (PBF) is a high-performance, water-cooled, uranium-fueled reactor, designed to operate at powers of up to 40 megawatts for time intervals up to 48 hours. The facility is used to provide operating information in support of DOE's light-water reactor safety program.

The Test Reactor Area (TRA) contains six reactors (three test reactors and three low-power reactors). Of the three test reactors, only one is operating: the Advanced Test Reactor (ATR). The other two, the Materials Testing Reactor (MTR) and the Engineering Test Reactor (ETR), were decommissioned in 1974 and 1981, respectively. The ATR provides research data on the performance of reactor materials and equipment components under conditions of high neutron flux. This research is in support of DOE's reactor development program. Also, the facilities at TRA have occasionally been made available to private organizations and other government agencies for research purposes.

TSF, part of TAN, is used in a support role for materials examination and repair, fabrication and assembly of the Loss of Fluid Test (LOFT) Mobile Test Assembly, and various reactor safety studies. Remote disassembly and reassembly of large radioactive components are performed in the Hot Shop Area. Activities in the Warm Shop at TSF are limited to the handling of only slightly radioactive materials.

Auxiliary Reactor Area-1 (ARA-1) is presently used for the operation of research and laboratory facilities and a Hot Cell. The Hot Cell is used to prepare test specimens for use in the various INEL reactors.

The Radioactive Waste Management Complex (RWMC) is one of the three principal waste handling facilities at INEL (the other two are the ANL-W Radioactive Scrap and Waste Facility and the Idaho Chemical Processing Plant). Waste from INEL and other DOE facilities, such as Rocky Flats, is packaged and stored at RWMC.

Exxon Nuclear Idaho Company, Idaho Chemical Processing Plant

The three major activities at the Idaho Chemical Processing Plant (ICPP) are irradiated fuel storage, fuel reprocessing, and waste calcination. Spent fuel from INEL reactors and other domestic and foreign research reactors is either stored at ICPP or converted to uranium oxide powder and shipped to Oak Ridge National Laboratory (ORNL) or Portsmouth. In addition, the ICPP contains the Waste Calcining Facility (WCF), which is used to convert high-level radioactive liquid waste to solid form.

Argonne National Laboratory-West Facilities

The Argonne National Laboratory-West (ANL-W) currently has five operational complexes: the Experimental Breeder Reactor No. 2 (EBR-II), the Transient Reactor Test Facility (TREAT), the Zero Power Facilities (ZPR-6, ZPR-9, and ZPPR), the Hot Fuels Examination Facility (HFEF), and the Laboratory and Office (L&O) support complex. All of these complexes provide support services for DOE's Fast Breeder Reactor (FBR) research program.

Westinghouse Electric Corporation

The Naval Reactor Facility (NRF), located 22 kilometers west and north of the ANL-W area, is operated by Westinghouse Electric Corporation. The facility serves as a testing area for prototype naval reactors and as a disassembly and inspection area for expended reactor cores. The prototype reactors are also used as training centers for naval reactor operators. Three operating reactors and the Expended Core Facility (ECF) are located in this area. These include the Large Ship Reactors (A1W), the Submarine Thermal Reactor (S1W), and the Natural Circulation Reactor (S5G).

2.6.3 Radionuclide Emissions and Existing Control Technology

Measurements of airborne releases at INEL have been consolidated and are presented in Table 2.6-1. The majority of emissions are attributable to the operation of the ATR and the ETR (dismantled in 1981) in the Test Reactor Area. These releases include argon-41, a majority of reported isotopes of xenon, cesium-138, barium-139, krypton-85, krypton-85m, krypton-87, and rubidium-88. TREAT accounts for the xenon-133 emissions, and activities at ICPP are responsible for exhausting tritium and krypton-85. EBR-II releases 50 percent of the total site xenon-135 emissions.

Releases from the ETR and ATR facilities are not treated. Other facilities at INEL, however, use multiple or single HEPA filters and, occasionally, charcoal absorbers. Areas using such control technologies include the Zero Power Facilities, TREAT, NRF facilities, PBF, and ARA-1.

2.6.4 Health Impact Assessment of Idaho National Engineering Laboratory

For the purpose of the dose/health effects assessment, it is assumed that all particulates released from the site are respirable. The assessment is based on all emissions being combined into one point source midway between the TRA and ICPP areas at a height of 1 meter above the ground. Actual site boundary distances from the assumed point source were used in the calculations.

Radiation dose rates are given in Table 2.6-2. The nearby individuals are located 19500 m north of the assumed release point. Air immersion is the major pathway contributing to the individual dose equivalent rate.

The fatal cancer risks are given in Table 2.6-3. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I. The pathway with the highest contribution to the fatal cancer risk is ingestion.

Table 2.6-1. Radionuclide emissions from the Idaho National Engineering Laboratory, 1981

Radionuclide	Emissions (Ci/y)
Silver-110m	8.5E-7
Argon-41	2.5E+3
Barium-131	2.2E-9
Barium-139	1.6E+2
Barium-Lanthanum-140	3.4E-5
Beryllium-7	1.3E-5
Bromine-82	9.0E-1
Carbon-14	1.7E-1
Cerium-141	1.7E-6
Cerium-144	3.9E-4
Cobalt-57	1.6E-8
Cobalt-58	3.6E-5
Cobalt-60	2.3E-4
Cesium-134	6.0E-5
Cesium-137	8.6E-3
Cesium-138	1.7E+1
Chromium-51	2.8E-5
Europium-152	6.0E-7
Europium-154	7.7E-6
Europium-155	1.5E-6
Tritium-3	4.0E+2
Hafnium-181	1.1E-5
Iodine-129	3.7E-2
Iodine-131	5.5E-2
Iodine-133	2.0E-6
Krypton-85	5.9E+4
Krypton-85m	2.2E+2
Krypton-87	8.7E+2
Krypton-Rubidium-88	8.0E+2
Manganese-54	7.3E-6
Niobium-95	2.5E-5
Promethium-144	3.7E-4
Plutonium-238	7.4E-5
Plutonium-239	1.8E-5
Ruthenium-103	1.4E-6
Ruthenium-Rhodium-106	7.7E-2
Antimony-122	1.2E-7

Table 2.6-1. Radionuclide emissions from the Idaho National Engineering Laboratory, 1981 (continued)

Radionuclide	Emissions (Ci/y)
Antimony-125	1.9E-1
Strontium-90	4.1E-3
Tantalum-182	1.9E-7
Tellurium-132	1.6E-7
Technetium-99m	1.0E-4
Tin-113	1.8E-7
Xenon-133	1.6E+2
Xenon-135	8.0E+2
Xenon-135m	4.2E+2
Xenon-138	2.5E+3
Zirconium-95	1.9E-6

Table 2.6-2. Radiation dose rates from radionuclide emissions from the Idaho National Engineering Laboratory

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Pulmonary	3.1E-2	1.7E-1
Endosteum	3.1E-2	2.6E-1
Red marrow	2.5E-2	1.9E-1
Breast	2.4E-2	1.4E-1
Thyroid	1.2E-1	5.5

Table 2.6-3. Fatal cancer risks due to radionuclide emissions from the Idaho National Engineering Laboratory(a)

Source	Lifetime risk to nearby individuals	Regional population (Fatal cancers/y of operation)
INEL	5E-7 (2E-7)	6E-5 (3E-5)

(a)The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

2.7 Lawrence Livermore National Laboratory; Livermore, California

2.7.1 General Description

The Lawrence Livermore National Laboratory is located about 64 kilometers east of San Francisco, California, in the Livermore Valley of eastern Alameda County, approximately 5 kilometers east of the City of Livermore. The site covers an area of 2.54 km^2 and is surrounded by open agricultural areas on the north, east, west, and part of the south side. Sandia Laboratories, Livermore, is located on adjoining property to the south. Materials testing and high-explosives diagnostic work is conducted at a remote site, Site 300, located on a 27 km^2 site 16 kilometers southeast of Livermore.

In addition to its primary role of nuclear weapons research and development, Lawrence Livermore National Laboratory conducts research programs in the areas of magnetic fusion, nonnuclear energy, laser fusion, laser isotope separation, and biomedical research.

2.7.2 Description of Facility

There are five principal facilities that release radioactivity into the air at Lawrence Livermore Laboratory.

Light Isotope Handling Facility (Building 331)

Tritium is the principal nuclide released from this facility which carries out research and development in the area of light isotopes. The two stacks from this facility are monitored.

Insulated Core Transfer Accelerator (ICT) (Building 212)

The ICT accelerator is an air-insulated variable energy machine which accelerates protons and deuterons up to 500 keV. The accelerator uses tritium targets for production of 14 MeV neutrons in support of the Magnetic Fusion Energy Program. The effluent is continuously monitored.

Electron Positron Linear Accelerator (LINAC) (Building 194)

Operation of the 100 MEV LINAC for neutron physics research produces activation of nitrogen, oxygen, and dust particles in the air of the facility. The effluent stream is continuously monitored before release to the atmosphere from a 30-meter high stack.

Decontamination Facility (Building 419)

The radioactivity in air effluents originates from various decontamination operations. Stack effluents are continuously sampled.

Solid Waste Disposal Facility (Building 292)

Radioactive solid waste packaging, holding, and shipping activities are conducted at this facility. Transfer and compacting operations of dry waste may result in particulate activity being released into the facility ventilation and process air. During operations, the stack effluent is sampled.

2.7.3 Radionuclide Emissions and Existing Control Technology

Table 2.7-1 identifies radioactive emissions from the facilities at Lawrence Livermore Laboratory in 1981. For the purpose of this analysis, all emissions in 1981 are assumed to be released from Building 194 from a 30-meter stack.

Radionuclide emissions for the period 1979 to 1981 are shown in Table 2.7-2.

Tritium emissions from the Light Isotope Handling Facility (Building 331), the Insulated Core Transfer Accelerator (Building 212), and the Solid Waste Disposal Facility (Building 292) are released without treatment. HEPA filters are used to reduce emissions of radioactive particulates from the Electron Positron Linear Accelerator (Building 194), the Decontamination Facility (Building 419), and the Solid Waste Disposal Facility (Building 292). Activation products from the Electron Positron Linear Accelerator are released without treatment.

2.7.4 Health Impact Assessment of Lawrence Livermore National Laboratory

The estimated annual radiation doses resulting from radionuclide emissions in 1981 from Lawrence Livermore National Laboratory are listed in Table 2.7-3. Nearby individuals are located 590 meters east-northeast of the assumed release point (Building 194). The predominant exposure pathway is ingestion and primarily from tritium. The total population within an 80-km radius of the site is 4.6 million.

Table 2.7-4 shows the estimates of the lifetime risk to nearby individuals and the number of fatal cancers to the regional population from these doses. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I.

Table 2.7-1. Radionuclide emissions from Lawrence Livermore National Laboratory, 1981 (Ci/y)

Radionuclide	Building					
	331	292	212	194	419	Totals
Tritium	2.6E+3	4.4E+1	2.3E+1			2.6E+3
Nitrogen-13				1.7E+2		1.7E+2
Oxygen-15				1.7E+2		1.7E+2
Plutonium-239(a)				4.2E-6	9.0E-7	5.1E-6
Strontium-90(b)				5.5E-5	1.7E-5	7.2E-5

(a)Reported as "Unidentified Alpha."
(b)Reported as "Unidentified Beta + Gamma."

Table 2.7-2. Radionuclide emissions from the Lawrence Livermore National Laboratory, 1979 to 1981 (Ci/y)

Radionuclide	1979	1980	1981
Argon-41	3.8E+2	1.6E+2	NR
Tritium	4.5E+3	2.3E+3	2.6E+3
Nitrogen-13	5.0E+2	9.9E+2	1.7E+2
Oxygen-15	3.3E+2	6.6E+2	1.7E+2
Plutonium-239(a)	7.2E-10	NR	5.1E-6
Strontium-90(b)	6.0E-5	4.7E-5	7.2E-5

(a)Reported as "Unidentified Alpha."
(b)Reported as "Unidentified Beta + Gamma."
NR None reported.

Table 2.7-3. Radiation dose rates from radionuclide emissions from the Lawrence Livermore National Laboratory, 1981

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Intestine wall	1.6	7.5
Red marrow	1.3	5.6
Kidneys	1.3	5.8

Table 2.7-4. Fatal cancer risks due to radionuclide emissions from the Lawrence Livermore National Laboratory, 1981(a)

Source	Lifetime risk to nearby individuals		Regional population (Fatal cancers/y of operation)	
LLNL	3E-5	(1E-5)	2E-3	(6E-4)

(a) The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

2.8 Los Alamos National Laboratory; Los Alamos, New Mexico

2.8.1 General Description

The Los Alamos National Laboratory (LANL) is a multidisciplinary facility located in north-central New Mexico. The site is about 100 kilometers north-northeast of Albuquerque and 40 kilometers northwest of Santa Fe. LANL is one of the prime research and development facilities in DOE's nuclear weapons program. In addition to national defense programs, activities at Los Alamos include research in the physical sciences, energy resources (both nuclear and nonnuclear) and applied programs, and biomedical and environmental studies. Facilities for these programs are dispersed widely over the site which is separated into a number of technical areas (TAs).

A substantial portion of LANL's reported emissions may be attributed to operations at the Meson Physics Facility (TA-53), the HP-Site (TA-33), the South Mesa Site (TA-3), the Omega Site (TA-2), and several other technical areas. Programs at these sites include the operation of an 800 MeV proton accelerator, laser and magnetic fusion activities, and research reactors--one of which is an 8 megawatt reactor--at the Omega site, and experiments using a tandem Van de Graaff accelerator.

2.8.2 Description of Facility

During 1981, effluents were released from more than 75 stacks located in 13 Technical Areas. A brief description of the activities conducted in these areas follows.

TA-2, Omega Site

Omega West Reactor, an 8 megawatt nuclear research reactor, is located here. It serves as a research tool in providing a source of neutrons for fundamental studies in nuclear physics and associated fields.

TA-3, South Mesa Site

In this main technical area of the Laboratory is the Administration Building that contains the Director's office and administrative offices and laboratories for several divisions. Other buildings house the Central Computing Facility, Personnel Administration Department offices, Materials Department, the science museum, Chemistry and Metallurgy Division, Physics Division, technical shops, cryogenics laboratories, a Van de Graaff accelerator, and cafeteria.

TA-21, DP-Site

This site has two primary research areas, DP West and DP East. DP West is concerned with tritium research. DP East is the high temperature chemistry site where studies are conducted on the chemical stability and interaction of materials at temperatures up to and exceeding 3300° C.

TA-33, HP-Site

Design and development of nuclear and other components of weapon systems are conducted here. A major tritium handling facility is located here. Laboratory and office space for the Geosciences Division related to the Hot Dry Rock Geothermal Project are also here.

TA-35, Ten Site

Nuclear safeguards research and development, which is conducted here, is concerned with techniques for nondestructive detection, identification, and analysis of fissionable isotopes. Research in reactor safety and laser fusion is also done here.

TA-41, W-Site

Personnel at this site are engaged primarily in engineering design and development of nuclear components, including fabrication and evaluation of test materials for weapons. Also located here is an underground laboratory that is used for physics experiments.

TA-43, Health Research Laboratory

The Biomedical Research Group does research here in cellular radiobiology, molecular radiobiology, biophysics, mammalian radiobiology, and mammalian metabolism. A large medical library, special counters used to measure radioactivity in humans and animals, and animal quarters for dogs, mice, and monkeys are also located in this building.

TA-46, WA Site

Applied photochemistry, which includes development of technology for laser isotope separation and laser-enhancement of chemical processes, is investigated at this site. Solar energy research, particularly in the area of passive solar heating for residences, is also done.

TA-48, Radiochemistry Site

Laboratory scientists and technicians at this site study nuclear properties of radioactive materials by using analytical and physical chemistry. Measurements of radioactive substances are made and "hot cells" are used for remote handling of radioactive materials.

TA-50, Waste Management Site

Personnel at this site have responsibility for treating and disposing of most contaminated liquid wastes received from Laboratory technical areas, for development of improved methods of waste treatment, and for containment of radioactivity removed by treatment. Radioactive waste is piped to this site for treatment from many of the technical areas.

TA-53, Meson Physics Facility

The Los Alamos Meson Physics Facility (LAMPF), a linear particle accelerator, is used to conduct research in the areas of basic physics, cancer treatment, materials studies, and isotope production.

TA-54, Waste Disposal Site

This is a disposal area for radioactive and toxic wastes.

TA-55, Plutonium Processing Facilities

Processing of plutonium and research in plutonium metallurgy are performed here.

2.8.3 Radionuclide Emissions and Existing Control Technology

Radioactive airborne releases at Los Alamos are summarized in Table 2.8-1. Emissions from all stacks within a Technical Area were summed, and the curie quantities of each radionuclide discharged within an Area are listed. Emissions include various isotopes of uranium and plutonium, americium-241, and activation products (beryllium-7, carbon-11, nitrogen-13, oxygen-15, phosphorus-32, argon-41, and tritium).

The Los Alamos site covers approximately 111 square kilometers and is nestled between several residential areas. Except for TA-33, the major source of tritium, all areas that contributed radioactive airborne contaminants are grouped along and within a few kilometers of the northern site boundary. Thus, all emissions were modeled as two point sources; one is tritium from TA-33, and the other consists of all the remaining effluents and is located roughly central to the other 12 TAs. The effluents listed in Table 2.8-1 were summed to provide the radioactive source terms for the two point sources. These quantities are listed in Table 2.8-2. All effluents are released from stacks with assumed heights of 30 meters.

The effluent control devices at LANL are determined by the types of activities conducted at each facility. Facilities in which transuranics are handled are equipped with glove boxes and hot cells and use negative pressure zonation to ensure containment of accidental releases. Exhaust streams from these facilities are passed through particulate filters (usually HEPA units, although bag filters and cyclones are also used) prior to discharge from building stacks.

Activated gases produced at facilities conducting fusion beam research are held up to allow the decay of short-lived isotopes. There are no effluent controls fitted to the test reactors at the Omega Site.

In 1983* the quantity of airborne activation products from the linear particle accelerator at the TA-53 Meson Physics Facility increased about 85 percent (about 213,000 curies more than in 1982) due to higher operating levels. These activation products include the following short half-life (2 to 20 minutes) radionuclides: carbon-11, nitrogen-13, oxygen-14, oxygen-15, argon-41, gold-192, and mercury-195.

2.8.4 Health Impact Assessment of Los Alamos National Laboratory

The health risk assessment performed for this facility is summarized in Tables 2.8-3 and 2.8-4. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I. The assessment was based on all emissions being combined into two point sources: those from the TA33 site, and those from a hypothetical stack that was considered the source for all other site emissions. The health effects are reported separately for these two emission sources. The nearby individuals with respect to the TA33 source are located 930 m southwest of the stack, while the nearby individuals with respect to the combined area source are located 2100 m south-southwest of the hypothetical stack. The population within the 80 km radius assessment area is 100,000 people.

Los Alamos* estimates the dose to the most exposed nearby individuals to have increased to 34 mrem/y to the whole body during 1983, compared to 8.1 mrem/y in 1982. This increase is due both to the higher operating levels of the linear particle accelerator at the TA-53 Meson Physics Facility and recent construction of a residential dwelling near the site boundary, so that people are exposed for longer time to higher levels of airborne activation products. A dose of 34 mrem/y corresponds to a lifetime risk of 8E-4. The risk would be 2E-4 if a dose rate reduction factor of 2.5 for low-LET radiation, as described in Chapter 8, Volume I of this report is included.

---

*Los Alamos National Laboratory, Environmental Surveillance at Los Alamos During 1983, Los Alamos National Laboratory Report, LA-10100-ENV(UC-41), April 1984.

Table 2.8-1. Radionuclide emissions (Ci) from Los Alamos National Laboratory, 1981

Radionuclide	Technical Area 2	3	21	33	35	41	43
Tritium		9.0E+2	1.1E+2	6.1E+3		1.3E+2	
Beryllium-7							
Carbon-11							
Nitrogen-13							
Oxygen-15							
Phosphorus-32							2.0E-5
Argon-41	3.0E+2						
Iodine-131		4.4E-5					
Uranium-235		1.8E-6	1.0E-3				
Uranium-238		1.6E-4					
Uranium-235/238		5.3E-5					
Plutonium-239			6.2E-6		2.7E-7		3.7E-7
Plutonium-238/239		4.0E-5	5.9E-6				
Americium-241			2.9E-7				
MFP		1.7E-4	2.8E-6				

Radionuclide	Technical Area 46	48	50	53	54	55
Tritium				6.6		
Beryllium-7				3.9E+1		
Carbon-11				1.3E+5		
Nitrogen-13				2.5E+4		
Oxygen-15				2.0E+5		
Phosphorus-32						
Argon-41				1.1E+3		
Iodine-131						
Uranium-235		2.3E-6				
Uranium-238	1.4E-5					
Uranium-235/238						
Plutonium-239		1.3E-6	1.6E-6		9.0E-9	4.9E-8
Plutonium-238/239			1.2E-7			4.8E-8
Americium-241						
MFP		1.4E-3	2.3E-5			

MFP Mixed fission products.

Table 2.8-2. Radionuclide emissions (Ci) from Los Alamos National Laboratory, 1981

Radionuclide	Technical Area 33	All other TAs[a]
Tritium	6.1E+3	1.1E+3
Beryllium-7		3.9E+1
Carbon-11		1.3E+5
Nitrogen-13		2.5E+4
Oxygen-15		2.0E+5
Phosphorus-32		2.0E-5
Argon-41		1.4E+3
Iodine-131		4.4E-5
Uranium-235		1.0E-3
Uranium-238		1.7E-4
Uranium-235, -238		5.3E-5
Plutonium-239		9.8E-6
Plutonium-238, -239		4.6E-5
Americium-241		2.9E-7
MFP		1.6E-3

(a)Technical Areas: 2, 3, 21, 35, 41, 43, 46, 48, 50, 53-55. Quantities summed from Table 2.7-1.

MFP Mixed fission products.

Table 2.8-3. Radiation dose rates from radionuclide emissions from the Los Alamos National Laboratory

	From TA33 source		From all other sources	
Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Endosteum	5.4E-1	1.4	1.1E+1	6.2E+1
Red marrow	6.8E-1	1.8	1.1E+1	5.9E+1
Breast	6.8E-1	1.8	9.1	5.1E+1

Table 2.8-4. Fatal cancer risks due to radioactive emissions from the Los Alamos National Laboratory(a)

Source	Nearby individuals (Lifetime risk)		Regional population (Total cancers/y of operation)	
TA33	1E-5	(5E-6)	5E-4	(2E-4)
All other sites	2E-4	(6E-5)	1E-2	(5E-3)

(a) The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

2.9 Oak Ridge Reservation; Oak Ridge, Tennessee

2.9.1 General Description

The Oak Ridge Reservation is located in northeastern Tennessee, approximately 35 kilometers west of Knoxville, Tennessee. It is in a valley between the Cumberland and Great Smokey Mountains and consists of approximately 150 square kilometers.

With the exception of the City of Oak Ridge (located on the northeastern boundary), the land within 8 kilometers of the Reservation is predominantly rural, used mainly for residences, small farms, and pasture. Approximately 690,000 people live within an 80 kilometer radius of the site.

2.9.2 Description of Facility

The three major facilities at the Oak Ridge Reservation are the Oak Ridge National Laboratory (ORNL), the Oak Ridge Gaseous Diffusion Plant (ORGDP), and the Y-12 Plant. Also located on the reservation are the Comparative Animal Research Laboratory and the Oak Ridge Associated Universities.

Oak Ridge National Laboratory

ORNL is a multipurpose research laboratory involved in basic and applied research in all areas related to energy. These research facilities consist of nuclear reactors, chemical pilot plants, research laboratories, and support facilities.

Oak Ridge Gaseous Diffusion Plant

The Oak Ridge Gaseous Diffusion Plant, a complex of production, research, development, and support facilities, has the primary function to enrich uranium hexafluoride (UF_6) in the uranium-235 isotope.

Y-12 Plant

The Oak Ridge Y-12 Plant has four primary responsibilities: (1) production of nuclear weapons components, (2) fabrication support for weapons design, (3) support for the Oak Ridge National Laboratory, and (4) support and assistance to other government agencies. The Y-12 Plant conducts activities which include production of lithium compounds, recovery of enriched uranium from scrap material, and fabrication of uranium into finished parts and assemblies. Fabrications operations include vacuum casting, arc melting, powder compaction, rolling, forming, heat treating, machining, inspection, and testing.

Oak Ridge Associated Universities

The Oak Ridge Associated Universities (ORAU) conduct research in areas such as biological chemistry, immunology, nuclear medicine, and radiochemistry. Radionuclides are handled in encapsulated or liquid form and the potential for producing gaseous effluents is very small.

2.9.3 Radionuclide Emissions and Existing Control Technology

Oak Ridge National Laboratory

The central radioactive gas disposal facilities release tritium, iodine-131, and krypton and xenon from radioisotope separations, reactor operations, and laboratory procedures. The gases undergo HEPA filtration at their source prior to discharge. The stack is constantly monitored and sampled.

The stack servicing the High Flux Isotope Reactor and the Transuranic Processing Plant releases fission product gases resulting from the chemical separation of curium and californium and from reactor operations. Process effluent gases undergo HEPA filtration.

Isotope separations and chemistry laboratory operations are the principal source of effluents. Uranium and plutonium are present in airborne effluent from the electromagnetic isotope separations facility. There are 14 exhaust points from this facility. All effluents are exhausted through one or two stages of HEPA filtration. Oil traps are also used.

A tritium target fabrication building releases small amounts of tritium from target preparation operations.

HEPA filters are used to reduce particulate activity from the transuranic research and the metal and ceramics laboratories. The effluents are monitored for alpha activity.

Oak Ridge Gaseous Diffusion Plant

The principal sources of release from ORGDP are the drum dryers in the decontamination facilities, which are in the uranium system, and the purging of light contaminants from the purge cascade. During 1977, the old purge cascade which used sodium fluoride and alumina traps to reduce emissions was replaced by a new purge cascade vent which has a KOH gas scrubber in the emission system.

Y-12 Plant

Many of the procedures conducted at the Y-12 Plant release particulate activity into the room exhaust air. Laboratory and room air exhaust systems are equipped with filtration systems which may include prefilters, HEPA filters, or bag filters.

The principal atmospheric emissions of radionuclides are uranium-234 and uranium-238 (depleted) from the Y-12 Plant and tritium, krypton-85, and xenon-133 from the Oak Ridge National Laboratory. Table 2.9-1 summarizes the radioactive airborne emissions from the Oak Ridge facilities for 1981. For purposes of analysis, the total radioactive emissions are assumed to be released from a vent 10 meters in height at the Y-12 plant. One-half the uranium-234 is assumed to be Class Y and one-half Class W; all uranium-238 is assumed to be Class Y. Table 2.9-2 compares the radioactive emissions from Oak Ridge for the years 1979-1981.

Table 2.9-1. Radionuclide emissions from Oak Ridge Reservation, 1981 (Ci/y)

Radionuclide	ORAU	ORGDP	ORNL	Y-12	1981 Total
Carbon-14	1.2E-3	-	-	-	1.2E-3
Tritium	5.2E-3	-	1.1E+4	-	1.1E+4
Iodine-125	2.5E-4	-	-	-	2.5E-4
Iodine-131	2.0E-4	-	6.0E-1		6.0E-1
Krypton-85	-	2.5E+1	6.6E+3	-	6.6E+3
Plutonium-239(a)	-	-	7.8E-8	-	7.8E-8
Technetium-99	-	3.6E-2	-	-	3.6E-2
Uranium-234	-	3.7E-3	-	1.2E-1	1.2E-1
Uranium-235	-	1.2E-4	-	-	1.2E-4
Uranium-236	-	2.4E-5	-	-	2.4E-5
Uranium-238	-	8.1E-4	-	4.0E-2(b)	4.0E-2(b)
Xenon-133	2.0E-3	-	3.2E+4	-	3.2E+4

(a) Reported as "Unidentified Alpha."
(b) Preliminary estimate.

ORAU	Oak Ridge Associated Universities.
ORGDP	Oak Ridge Gaseous Diffusion Plant.
ORNL	Oak Ridge National Laboratory.

Table 2.9-2. Radionuclide emissions from the Oak Ridge Reservation, 1979 to 1981 (Ci/y)

Radionuclide	1979	1980	1981
Carbon-14	2.6E-4	1.6E-4	1.2E-3
Tritium	5.1E+3	1.5E+4	1.1E+4
Iodine-125	-	2.9E-4	2.5E-4
Iodine-131	3.0E-1	2.3E-1	6.0E-1
Krypton-85	1.1E+4	8.8E+3	6.6E+3
Plutonium-239(a)	4.8E-6	4.9E-6	7.8E-8
Technetium-99	1.4	8.8E-1	3.6E-2
Uranium-234	1.1E-1	1.9E-1	1.2E-1
Uranium-235	1.4E-3	8.3E-4	1.2E-4
Uranium-236	2.1E-4	1.2E-4	2.4E-5
Uranium-238	7.0E-3	4.1E-3	4.0E-2(b)
Xenon-133	5.1E+4	4.2E+4	3.2E+4

(a) Reported as "Unidentified Alpha."
(b) Preliminary estimate.

2.9.4 Health Impact Assessment of Oak Ridge Reservation

The health impact assessment resulting from radionuclide emissions in 1981 from the Oak Ridge Reservation is listed in Tables 2.9-3 and 2.9-4. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I. The nearby individuals are located 980 meters north of the assumed release point location at the Y-12 plant. The predominant exposure pathway is inhalation. The doses are primarily due to uranium-234 and tritium.

Table 2.9-3. Radiation dose rates from radionuclide emissions from the Oak Ridge Reservation, 1981

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Pulmonary	50	212
Thyroid	9.3	15
Endosteum	7.6	22
Kidney	5.4	15

Table 2.9-4. Fatal cancer risks due to radionuclide emissions from the Oak Ridge Reservation, 1981[a]

Source	Lifetime risk to nearby individuals	Regional population (Fatal cancers/y of operation)
Oak Ridge Reservation	1E-4 (1E-4)	8E-3 (6E-3)

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

2.10 Paducah Gaseous Diffusion Plant; Paducah, Kentucky

2.10.1 General Description

The Paducah Gaseous Diffusion Plant (PGDP) is a uranium enrichment gaseous diffusion plant with a uranium hexafluoride (UF_6) manufacturing plant and various other support facilities. The plant is located in McCracken County, Kentucky, about 6 kilometers south of the Ohio River and 32 kilometers east of the confluence of the Ohio and Mississippi Rivers. The Paducah uranium enrichment cascade consists of 1812 stages housed in five buildings with a total ground coverage of about 0.3 km^2. Including support facilities, the plant has a total complement of about 30 permanent buildings.

Except for the large raw water treatment plant, all buildings are contained within a 3 km^2 fenced area. A buffer area of at least 365 meters in depth exists on all sides of the fenced area. Beyond the DOE-owned buffer is an extensive wildlife management area leased or deeded to the Commonwealth of Kentucky. There are no residences within 900 meters of any of the process buildings. The nearest incorporated towns are Metropolis, Illinois, located 8 kilometers to the northeast; and LaCenter, Kentucky, located 18 kilometers southwest. Paducah, Kentucky, a city of 35,000, is located 19 kilometers east of the plant. The population within a 80 km radius is 450,000.

2.10.2 Description of Facility

The primary plant, the diffusion cascade, contains a physical process in which UF_6 is fed into the system, pumped through the diffusion stages, and eventually is removed as UF_6. The product is enriched in the fissionable uranium-235 isotope and the "tails" are withdrawn at the bottom as UF_6 depleted in uranium-235. The process pumps require electric power, lubrication, and air for cooling. The compressed gases are cooled by heat exchange fluid which is, in turn, cooled by recirculating cooling water.

The manufacturing building or Feed Plant uses hydrogen, anhydrous hydrogen fluoride (HF), and uranium oxide (UO_3) to produce the UF_6 that is fed into the diffusion cascade.

The Uranium Recovery and Chemical Processing Facility conducts operations that involve pulverizing and screening of uranium salts.

At the Metals Plant, depleted UF_6 from the Cascade is reacted with HF to convert it to UF_4 which is more easily stored.

2.10.3 Radionuclide Emissions and Existing Control Technology

All the stages in the enrichment cascade are contained within five buildings. The prime source of emissions is from the purge cascade which is used for removal of light contaminants from the process stream. These contaminants, which consist of isotopes of uranium and technetium-99, are released from the diffusion cascade building stack, which is sampled regularly.

Gaseous emissions from fluorination operations, which convert UF_4 to UF_6, are passed through a series of waste treatment systems that include cold traps, fluid bed absorbers, and sintered metal filters. HEPA and bag filters are also used to treat other emissions from the Feed Plant. Bag filters are used to reduce airborne emissions from the Uranium Recovery and Chemical Processing Facility.

Radioactive material emissions are from two discharge points, C-310 stack and vent C-400 (Table 2.10-1). Releases for 1981 have increased when compared to the average for 1979-1981, except for technetium which has decreased (Table 2.10-2). All releases were assumed to be at ground level from vent C-400 for calculational purposes. Releases for 1982 from the C-400 stack are expected to be an order of magnitude smaller, due to recent improvements in emission controls. Also, a new 200-ft stack will be used for releases from the former C-310 stack. All uranium emissions are assumed to be Class W.

Table 2.10-1. Radionuclide emissions from the Paducah Plant, 1981 (Ci/y)

Radionuclide	C-310	C-400	Total 1981
Uranium-234	5.5E-4	1.0E-2	1.0E-2
Uranium-235	2.9E-5	5.0E-4	5.3E-4
Uranium-236	3.6E-7	3.0E-5	3.0E-5
Uranium-238	4.7E-4	3.9E-2	3.9E-2
Technetium-99	6.1E-3	--	6.1E-3

Table 2.10-2. Radionuclide emissions from the Paducah Plant, 1979 to 1981 (Ci/y)

Radionuclide	1979	1980	1981
Technetium-99	6.1E-2	5.3E-2	6.1E-3
Uranium-234	2.7E-3	6.5E-4	1.1E-2
Uranium-235	1.7E-4	3.5E-5	5.3E-4
Uranium-236	3.9E-5	4.2E-7	3.0E-5
Uranium-238	7.7E-3	5.5E-4	4.0E-2

2.10.4 Health Impact Assessment of the Paducah Plant

The estimated annual radiation dose and fatal cancer risks from plant emissions in 1981 are listed in Tables 2.10-3 and 2.10-4. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I. The nearby individuals are located 1100 meters north of the release location. The predominant exposure pathway is that of inhalation. The annual radiation dose is primarily from uranium-234 and uranium-238.

Table 2.10-3. Radiation dose rates from radionuclide emissions from the Paducah Plant, 1981

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Pulmonary	4.7	3.4
Endosteum	7.1	1.3E+1
Thyroid	2.0E-1	4.3E-1
Kidney	3.6	6.7
Red marrow	5.1E-1	9.3E-1

Table 2.10-4. Fatal cancer risks due to radionuclide emissions from the Paducah Plant, 1981[a]

Source	Lifetime risk to nearby individuals		Regional population (Fatal cancers/y of operation)	
Paducah Plant	1E-5	(1E-5)	1E-4	(1E-4)

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

2.11 Portsmouth Gaseous Diffusion Plant; Piketon, Ohio

2.11.1 General Description

The Portsmouth Gaseous Diffusion Plant is operated by Goodyear Atomic Corporation, a subsidiary of the Goodyear Tire and Rubber Company. The principal process in the plant is the separation of uranium isotopes by gaseous diffusion. Support operations include the feed and withdrawal of material from the primary process; treatment of water for both sanitary and cooling purposes; decontamination of equipment removed from the plant for maintenance or replacement; recovery of uranium from various waste materials; and treatment of sewage wastes and cooling water blowdown.

The Portsmouth Gaseous Diffusion Plant is located in sparsely populated, rural Pike County, Ohio, on a 16.2-km^2 site about 1.6 km east of the Scioto River Valley at an elevation approximately 36.6 m above the Scioto River flood plain. The terrain surrounding the plant, except for the Scioto River Flood Plain, consists of marginal farm land and densely forested hills. The Scioto River Valley is farmed extensively, particularly with grain crops.

Several small communities, such as Piketon, Wakefield, and Jasper, lie within a few kilometers of the plant. The nearest community with a substantial population is Piketon (population: 1700), which is approximately 8 km north of the plant on U.S. Route 23. Population centers within 50 km of the plant are Portsmouth (population: 26,000), 32 km south; Chillicothe (population: 23,000), 34 km north; Jackson (population: 7,000), 29 km east; and Waverly (population: 5,000), 11 km north. The total population of the area lying within an 80 km radius of the plant is approximately 600,000.

2.11.2 Description of Facility

The Portsmouth Gaseous Diffusion Plant consists of a 4020-Stage Enrichment Cascade and a 60-Stage Purge Cascade for enriching UF_6 in the U-235 isotope. The Portsmouth Cascade is housed in three processing buildings (X-326, X-330, and X-333), and is the only domestic enrichment plant capable of producing very highly enriched uranium (97.65 percent U-235). A Cold-Recovery System is used to recover UF_6 from the system and to purge light contaminants (air, N_2, HF, and coolant) from the diffusion cascade.

2.11.3 Radionuclide Emissions and Existing Control Technology

The gaseous radioactive discharges for 1981 representing all cold-recovery activities for the plant are shown in Table 2.11-1. The total air emissions of radioactive material have decreased for most radionuclides from 1979 to 1981. The most significant release point for 1981 is X-326 Top Purge Vent. This release point discharged approximately 84 percent of the total plant release, as shown in Table 2.11-1. Uranium emissions are assumed to be Class W.

Emissions from the Cold-Recovery System are passed through sodium fluoride traps before release. The X-326 Purge Vent is equipped with alumina traps to reduce airborne emissions.

2.11.4 Health Impact Assessment of Portsmouth Plant

The estimated annual radiation doses and fatal cancer risks resulting from emissions in 1981 at the Portsmouth Plant are listed in Tables 2.11-3 and 2.11-4. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I. The nearby individuals are located 1300 meters west-northwest of the release location. The predominant exposure pathway is that of inhalation. The doses are primarily from uranium-234.

Table 2.11-1. Atmospheric emissions of radionuclides from the Portsmouth Plant, 1981

Source/Radionuclide	Emissions (Ci/y)
Top Purge Cascade	
X-326 Top Purge Vent	
Protactinium-234M	3.7E-2
Technetium-99	1.0E-1
Thorium-234	3.7E-2
Uranium-234	8.5E-2
Uranium-235	2.5E-3
Uranium-236	3.4E-5
Uranium-238	1.4E-4
X-330 Cold Recovery System Vent	
Protactinium-234M	2.0E-2
Technetium-99	2.8E-3
Thorium-234	2.0E-2
Uranium-234	9.7E-4
Uranium-235	4.7E-5
Uranium-236	1.1E-6
Uranium-238	5.5E-4

Table 2.11-1. Atmospheric emissions of radionuclides from the Portsmouth Plant, 1981 (continued)

Source/Radionuclide	Emissions (Ci/y)
X-333 Cold Recovery	
X-333 Cold-Recovery System Vent	
Protactinium-234M	9.9E-4
Technetium-99	1.2E-3
Thorium-234	9.9E-4
Uranium-234	5.7E-4
Uranium-235	3.3E-5
Uranium-236	1.1E-6
Uranium-238	5.6E-4
X-744-G Oxide Sampling Facility	
Hood exhaust vent	
Protactinium-234M	1.0E-5
Thorium-234	1.0E-5
Uranium-234	4.6E-6
Uranium-235	2.3E-7
Uranium-236	4.5E-9
Uranium-238	2.4E-8

Table 2.11-2. Radionuclide emissions from the Portsmouth Plant, 1979 to 1981 (Ci/y)

Radionuclide	1979	1980	1981
Protactinium-234M	6.2E-2	4.0E-2	5.8E-2
Technetium-99	1.7E-1	2.1E-1	1.1E-1
Thorium-234	6.2E-2	4.0E-2	5.8E-2
Uranium-234	8.2E-2	2.2E-1	8.7E-2
Uranium-235	2.4E-3	6.7E-3	2.6E-3
Uranium-236	5.6E-4	1.1E-4	3.6E-5
Uranium-238	1.9E-3	1.4E-3	1.3E-3

Table 2.11-3. Radiation dose rates from radionuclide emissions from the Portsmouth Plant, 1981

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Pulmonary	6.9	11
Thyroid	2	7.9
Endosteum	11	35
Kidney	5.1	17
Red marrow	0.8	3

Table 2.11-4. Fatal cancer risks due to radioactive emissions from the Portsmouth Plant, 1981[a]

Source	Lifetime risk to nearby individuals		Regional population (Fatal cancers/y of operation)	
Portsmouth Plant	2E-5	(2E-5)	6E-4	(5E-4)

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

2.12 Rocky Flats Plant; Jefferson County, Colorado

2.12.1 General Description

The Rocky Flats Plant (RFP) is the prime DOE facility for the fabrication and assembly of plutonium and uranium components for nuclear weapons. The two programs at RFP that involve the handling of significant quantities of plutonium are component fabrication and assembly and plutonium scrap recovery. Fabrication operations use the metallurgical processes of casting, milling, machining, cleaning, and etching. These mechanical processes for producing weapons components generate plutonium scrap. The scrap is collected and recovered on the site.

Uranium in both the enriched and depleted forms is handled at RFP. Depleted uranium is utilized in component fabrication and is treated by many of the same metallurgical processes as plutonium. Enriched uranium is recovered from decommissioned weapons and is returned to DOE's enrichment facility at Oak Ridge for recycling.

The Rocky Flats Plant is located in Jefferson County, Colorado approximately 26 kilometers northwest of Denver. The facilities are located within a 1.55 km^2 security area which is situated on 26.5 km^2 hectares of Federally-owned land. The site is on the eastern edge of a geological bench, with the foothills of the Rocky Mountains to the west. The area immediately surrounding the plant is primarily agricultural or undeveloped. However, about 1.8 million people reside within 80 kilometers.

2.12.2 Description of Facility

The processes conducted at the plant use plutonium and uranium. Plutonium is stored in closed containers in a vault with an inert atmosphere. Ingots of plutonium taken from the vault undergo metallurgical processes which include reduction rolling, blanking, forming, and heat treating. Smaller pieces of plutonium are drilled or broken to provide samples for the Analytical Laboratory and for casting operations. The formed pieces are machined into the various components which are then assembled. Assembly operations include cleaning, brazing, marking, welding, weighing, matching, sampling, heating, and monitoring. Nuclear weapons are not assembled at this plant.

Solid residue generated during plutonium-related operations is recycled through one of two plutonium recovery processes; the process selected depends on the purity and content of plutonium in the residue. Both processes result in a plutonium nitrate solution from which the metal can be extracted. The recovered plutonium is returned to the storage vault for use in foundry operations. A secondary objective of the process is the recovery of americium-241.

Rocky Flats Plant also conducts operations involving the handling of uranium. Depleted uranium-alloy scrap is consolidated and recycled at one of the foundries. The depleted uranium alloys are ore-melted into ingots for further metallurgical processing. Rocky Flats also has the capabilities to machine and assemble enriched uranium pieces. Enriched uranium components, returned because of age, are disassembled. The enriched uranium is separated and then sent to Oak Ridge, Tennessee, for recycling.

Because of its toxicity, plutonium is stored and processed under strictly controlled conditions. Much of the plutonium processing equipment is enclosed in glove boxes with an inert, nitrogen atmosphere. The glove boxes are maintained at a slight negative pressure relative to the surrounding area. This allows ventilation air to flow toward areas of greater radioactive contamination instead of away from them.

2.12.3 Radionuclide Emissions and Existing Control Technology

Atmospheric emissions from the Rocky Flats Plant are listed in Table 2.12-1. Manufacturing operations at the site are reportedly responsible for 85 to 95 percent of the plutonium and uranium emissions and 55 percent of the tritium released. All particulates are assumed to be 1 micron in diameter.

Releases from the buildings at RFP are from short stacks and building vents. Given the relatively small size of the production area, the 26.5 km^2 site is considered to be a ground-level point source. For the purpose of our analysis, we have assumed that releases are from a point 2.5 kilometers from the northeastern site boundary.

Several of the release points are similar in release quantities. For comparison purpose and calculations, Building 771 - Main Plenum was selected. This point releases 54 percent of the plutonium-239, -240 and 3 percent of the uranium-233, - 234, -235. The most significant release site for uranium is Building 883, Duct B, which has approximately 19 percent of the total uranium emission.

A comparison of the emissions for the years 1979 to 1981 is given in Table 2.12-2.

Exhausts from buildings where plutonium and uranium are stored and processed are passed through multiple banks of HEPA filters prior to release to the atmosphere.

Table 2.12-1. Radionuclide emissions from the Rocky Flats Plant, 1981

Source/Radionuclide	Emissions (Ci)
Plutonium Analytical Laboratory	
Tritium	2.0E-2
Plutonium-239, -240	4.4E-7
Uranium-233, -234, -238	4.1E-7
Fabrication Assembly Building	
Building 707-106 Plenum	
Tritium	3.9E-3
Plutonium-239, -240	4.7E-8
Uranium-233, -234, -238	1.6E-7
Building 707-108	
Tritium	2.5E-3
Plutonium-239, -240	5.5E-8
Uranium-233, -234, -238	9.2E-8
Building 707-105	
Tritium	4.6E-3
Plutonium-239, -240	1.6E-7
Uranium-233, -234, -238	2.8E-7
Building 707-107	
Tritium	1.4E-2
Plutonium-239, -240	5.5E-8
Uranium-233, -234, -238	2.0E-7
Building 707-101/103	
Tritium	2.6E-3
Plutonium-239, -240	5.0E-8
Uranium-233, -234, -238	3.8E-8
Building 707-102/104	
Tritium	6.4E-3
Plutonium-239, -240	1.2E-8
Uranium-233, -234, -238	1.1E-8
Manufacturing	
371 N1 + N2	
Tritium	4.3E-3
Plutonium-239, -240	5.7E-8
Uranium-233, -234, -238	8.7E-8

Table 2.12-1. Radionuclide emissions from the Rocky Flats Plant, 1981 (continued)

Source/Radionuclide	Emissions (Ci)
Manufacturing (continued)	
371 South	
Tritium	1.6E-3
Plutonium-239, -240	1.6E-8
Uranium-233, -234, -238	1.7E-8
Building 771-Main Plenum	
Tritium	8.0E-2
Plutonium-239, -240	4.5E-6
Uranium-233, -234, -238	1.0E-6
Building 771C-Main Plenum	
Tritium	4.5E-5
Plutonium-239, -240	3.8E-7
Uranium-233, -234, -238	7.4E-8
Building 771C-Room Plenum	
Plutonium-239, -240	8.9E-7
Uranium-233, -234, -238	5.6E-8
374 Waste Treatment Facility	
374 Spray Dryer	
Tritium	7.6E-4
Plutonium-239, -240	5.0E-9
Uranium-233, -234, -238	5.2E-8
Building 774-202	
Tritium	1.8E-3
Plutonium-239, -240	7.8E-8
Uranium-233, -234, -238	2.0E-8
Manufacturing Building	
Building 776-250	
Tritium	1.5E-2
Plutonium-239, -240	1.2E-7
Uranium-233, -234, -238	2.0E-7
Building 776-206	
Tritium	1.2E-1
Plutonium-239, -240	5.0E-8
Uranium-233, -234, -238	1.9E-7

Table 2.12-1. Radionuclide emissions from the Rocky Flats Plant, 1981 (continued)

Source/Radionuclide	Emissions (Ci)
Manufacturing Building (continued)	
Building 776-201/203	
Tritium	8.4E-4
Plutonium-239, -240	3.1E-9
Uranium-233, -234, -238	1.8E-8
Building 776-205	
Tritium	3.8E-2
Plutonium-239, -240	1.0E-8
Uranium-233, -234, -238	2.8E-8
Building 776-204	
Tritium	1.5E-2
Plutonium-239, -240	1.1E-7
Uranium-233, -234, -238	5.6E-7
Building 776-251	
Tritium	1.7E-8
Plutonium-239, -240	4.8E-8
Uranium-233, -234, -238	1.7E-8
Building 776-252	
Plutonium-239, -240	2.7E-8
Uranium-233, -234, -238	1.9E-8
Building 776-202	
Plutonium-239, -240	4.1E-8
Uranium-233, -234, -238	2.9E-8
Plutonium Development Building	
Building 779-729 Plenum	
Tritium	2.1E-3
Plutonium-239, -240	3.1E-8
Uranium-233, -234, -238	1.0E-7
Building 779-782 Plenum	
Tritium	4.2E-2
Plutonium-239, -240	2.5E-7
Uranium-233, -234, -238	4.6E-7
Laundry	
Building 778 Laundry	
Plutonium-239, -240	7.4E-8
Uranium-233, -234, -238	4.5E-7

Table 2.12-1. Radionuclide emissions from the Rocky Flats Plant, 1981 (continued)

Source/Radionuclide	Emissions (Ci)
Waste Treatment Facility	
Building 374-Main	
Tritium	1.9E-2
Plutonium-239, -240	5.8E-8
Uranium-233, -234, -238	1.6E-7
Manufacturing Building	
Building 444-Ducts 2 and 3	
Uranium-233, -234, -238	9.2E-7
Building 444-Duct 1	
Uranium-233, -234, -238	1.0E-6
Building 444-Duct 5	
Uranium-233, -234, -238	2.0E-7
Building 447 Main	
Uranium-233, -234, -238	1.2E-6
Materials and Process Development Laboratory	
Building 865-East	
Uranium-233, -234, -238	1.8E-7
Building 865-West	
Uranium-233, -234, -238	7.0E-7
Manufacturing Building	
Building 881-Ducts 1, 2, 3 and 4	
Tritium	4.2E-2
Plutonium-239	3.6E-7
Uranium-233, -234, -238	2.6E-6
Building 881 (Ducts 5 and 6)	
Plutonium-239, -240	2.3E-7
Uranium-233, -234, -238	4.2E-6
Building 883-Duct A	
Uranium-233, -234, -238	7.0E-6
Building 883-Duct B	
Uranium-233, -234, -238	5.8E-6

Table 2.12-1. Radionuclide emissions from the Rocky Flats Plant, 1981 (continued)

Source/Radionuclide	Emissions (Ci)
Nuclear Safety Facility	
Building 886-875	
Plutonium-239, -240	1.2E-8
Uranium-233, -234, -238	2.3E-7
Equipment Decontamination Building	
Building 889-Main	
Plutonium-239, -240	1.5E-8
Uranium-233, -234, -238	8.8E-7
Assembly Building	
Building 991-985	
Plutonium-239, -240	8.8E-9
Uranium-233, -234, -238	1.6E-7
991 Main	
Plutonium-239, -240	3.2E-8
Uranium-233, -234, -238	8.2E-8

Table 2.12-2. Radionuclide emissions from the Rocky Flats Plant 1979 to 1981 (Ci/y)

Radionuclide	1979	1980	1981
Tritium	8.0E-1	7.8E-1	3.9E-1
Plutonium-239, 240	5.4E-6	1.2E-5	8.2E-6
Uranium-234	9.0E-6		
Uranium-238	2.5E-5		
Uranium-233, 234, and 238			3.0E-5
Uranium-233, 234		1.5E-5	
Uranium-238		1.4E-5	

2.12.4 Health Impact Assessment of Rocky Flats Plant

The estimated annual radiation doses and fatal cancer risks resulting from radionuclide emissions in 1981 from the Rocky Flats Plant are listed in Tables 2.12-3 and 2.12-4. The nearby individuals are located 2260 meters north northeast of the release location. The predominant exposure pathway is that of inhalation. The doses are primarily from uranium-233, -234, -238; and plutonium-239 and -240.

Table 2.12-3. Radiation dose rates from radionuclide emissions from the Rocky Flats Plant, 1981

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Endosteum	1.5E-2	1.6E-1
Pulmonary	1.2E-2	1.3E-1
Liver	2.8E-3	2.9E-2
Red Marrow	1.2E-3	1.2E-2

Table 2.12-4. Fatal cancer risks due to radioactive emissions from the Rocky Flats Plant, 1981

Source	Lifetime risk to nearby individuals	Regional population (Fatal cancers/y of operation)
Rocky Flats Plant	2E-8	3E-6

2.13 Savannah River Plant; Aiken, South Carolina

2.13.1 General Description

The Savannah River Plant (SRP) is located in South Carolina on the Savannah River, approximately 35 kilometers southeast of Augusta, Georgia, and 150 kilometers north-northwest of Savannah, Georgia. The site occupies an area of approximately 770 square kilometers and lies within portions of Aiken, Barnwell, and Allendale Counties of South Carolina.

The facilities at SRP are used primarily for the production of plutonium and tritium, the basic materials for the fabrication of nuclear weapons. Additional activities at Savannah River include the production of special nuclear materials for medical and space applications.

2.13.2 Description of Facility

SRP facilities are grouped into five major areas according to their operational functions in the plutonium recovery process. These areas and the major activities performed there include:

100 Area - three nuclear production reactors;

200 Area - plutonium and uranium separations, waste management;

300 Area - fuel and target fabrication;

400 Area - heavy water recovery and production;

700 Area (Savannah River Laboratory) - research and process development and pilot-scale demonstration projects.

100 Area - Nuclear Production Reactors

Of the five production reactors at SRP, only three (the P, K, and C reactors) are currently used for plutonium production. The other two, R and L, have been on standby status since 1964 and 1968, respectively. The L reactor is being upgraded and will be restarted in the fall of 1983. The impact of the L reactor restart is discussed in a later section. The three operating reactors are used to produce plutonium and tritium by the irradiation of uranium and lithium using heavy water (D_2O) as both primary coolant and neutron moderator. The heavy water is circulated in a closed system through heat exchangers.

200 Area - Separations and Waste Management Facilities

Nuclear fuel reprocessing takes place in the 200 Area, where the F and H Separations Facilities are sited. Plutonium is recovered in the F Area, and uranium and other special nuclear materials are recovered in the H Area.

Plutonium is recovered from irradiated uranium in the F-Canyon Building using the Purex solvent-extraction process. The recovery of enriched uranium from reactor fuel and the recovery of plutonium-238 from irradiated neptunium are done in the H-Canyon Building. Both activities are performed using a procedure similar to the Purex process. Tritium is recovered from irradiated lithium/aluminum targets in three other H Area buildings.

Solid and liquid wastes from this and other DOE facilities are stored between the F and H Separation Areas.

300 Area - Fuel and Target Fabrication

Fuel and target fabrication operations are conducted in three facilities: the Alloy Extrusion Plant, the Uranium Metal Element Fabrication Plant, and the Target Extrusion Plant. Support facilities include two test reactors and the Metallurgical Laboratory.

Tubular fuel and target elements are produced at the two target extrusion plants. Coextrusion is used to clad depleted uranium (0.2 percent uranium-235) fuel and target elements with aluminum or a mixture of lithium and aluminum. A low-power reactor and a subcritical test reactor are then used to test the fabricated reactor elements for cladding defects. These elements are then shipped to the production reactors in Area 100 for irradiation.

Once the elements have been irradiated by the SRP reactors, they are inspected in the Metallurgical Laboratory. The Metallurgical Laboratory facilities are also used to test materials produced in the 300 Area.

400 Area - Heavy Water Production and Recovery

Activities in the 400 Area include both the production and the recovery of heavy water (D_2O). These operations are performed in two distillation plants and one extraction plant. The Drum Cleaning Facility and Analytical Laboratory are used as support facilities.

Heavy water is produced from river water and recovered from contaminated reactor coolant. The D_2O is then shipped to the 100 Area where it is used both as moderator and primary coolant in the production reactors.

700 Area - The Savannah River Laboratory

Research and process development work supporting the overall mission of SRP is performed at the Savannah River Laboratory (SRL). Major activities in this area include:

- fabrication of fuel element and target prototypes,
- fabrication of radioisotopic sources for medical, space, and industrial applications,

- R&D on separations processes at the pilot-scale level,
- thermal and safety studies on reactor operations, and
- applied research in the areas of physics and the environmental sciences.

2.13.3 Radionuclide Emissions and Existing Control Technology

Annual emissions for all facilities at SRP are summarized by operational area in Table 2.13-1. Airborne releases and controls for each SRP area are described below.

100 Area - Nuclear Production Reactors

Carbon-14, argon-41, tritium, and various isotopes of krypton and xenon are the major radionuclides released from the three production reactors. Discharges range from tens of curies to hundreds of thousands of curies per year (Table 2.13-1).

All of the releases from the production reactors are from 60-meter stacks. All air exhausted from the reactor containment buildings is filtered through moisture separators, particulate filters, and carbon beds prior to release. Although these treatments are effective for particulates and radioiodine, they have little effect on the discharge of noble gases and tritium.

200 Area - Separations and Waste Management Facilities

Airborne releases from the 200 Area are from the separations facilities (the waste management facilities reportedly emit no radionuclides). Operations generating pollutants include the use of evaporators and furnaces and leakage in the process system. Major releases include tritium and activation and fission products (Table 2.13-1). Control technologies employed include either scrubbers, fiberglass filters, high-efficiency sand filters, or oxidation and moisture trapping.

300 Area - Fuel and Target Fabrication

Airborne effluents released from the 300 Area consist of natural uranium, unidentified alpha-emitters, and tritium. In 1981, there were no reported tritium or uranium releases. Off-gases from the Alloy Extrusion Plant and the Metallurgical Laboratory are passed through HEPA filters prior to discharge. Exhaust streams from the Uranium Metal Element Fabrication Plant, the Target Extrusion Plant, and the test reactors are vented directly from the buildings to ambient air without filtration. Discharges from the area are made from a variety of stacks and building vents, and release heights vary from 10 to 31 meters.

400 Area - Heavy Water Production and Recovery

Radioactive discharges from the 400 Area are composed entirely of tritium. The tritium released is from tritiated reactor coolant waters and represents less than 1 percent of the total tritium released at SRP during 1981. Releases from the 400 Area are monitored for some facilities and estimated for others. The releases are not treated prior to discharge. Discharges are from building vents and stacks; release heights range from 10 to 30 meters.

700 Area - Savannah River Laboratory

Airborne releases from SRL include cobalt-60, tritium, and iodine-131. The cobalt-60 is the only release of this nuclide reported for the site. All discharges from processing areas are filtered through at least two stages of HEPA filtration and a multilayered sand trap before discharge from a 50-meter stack.

Summary of Radioactive Emissions at SRP

The separations facilities and the reactor areas are responsible for the majority of radioactive releases at SRP. The production reactors release virtually all of the noble gases discharged at SRP and one-third of the tritium (see Table 2.13-1). Separations activities in the 200 Area result in the release of two-thirds of the tritium. Fuel reprocessing activities in the separations areas result in significant releases of activation products, fission products, and the transuranics. The size of all particles released is assumed to be 1 micron. Table 2.13-2 indicates the releases for 1979 to 1981.

SRP occupies a large area of 770 square kilometers. However, population densities in the vicinity of the site are relatively low. For this reason, SRP is considered to be a point source. The single stack from which releases are emitted is assumed to be 60 meters high and to be located in the center of the facility.

Table 2.13-1. Radionuclide emissions from the Savannah River Plant, 1981 (Ci/y)

Radionuclide	Area					Total
	100	200	300	400	700	
Americium-241[a]	4.4E-6	4.9E-4	3.6E-7	-	-	5.0E-4
Argon-41	6.2E+4	-	-	-	-	6.2E+4
Carbon-14	4.1E+1	2.8E+1	-	-	-	6.9E+1
Cerium-141	-	3.2E-4	-	-	-	3.2E-4
Cerium-144	-	2.6E-2	-	-	-	2.6E-2

Table 2.13-1. Radionuclide emissions from the Savannah River Plant, 1981 (Ci/y) (continued)

Radionuclide	Area					Total
	100	200	300	400	700	
Curium-244	–	1.6E-4	–	–	–	1.6E-4
Cobalt-60	–	–	–	–	8.9E-5	8.9E-5
Cesium-134	–	6.4E-4	–	–	–	6.4E-4
Cesium-137	–	3.1E-3	–	–	–	3.1E-3
Tritium	1.2E+5	2.3E+5	–	2.0E+3	1.5E+1	3.5E+5
Iodine-129(b)	4.5E-4	1.6E-1	–	–	5.0E-6	1.6E-1
Iodine-131	7.0E-3	3.7E-2	–	–	3.2E-3	4.7E-2
Krypton-85	–	8.4E+5	–	–	–	8.4E+5
Krypton-85m	1.3E+3	–	–	–	–	1.3E+3
Krypton-87	8.7E+2	–	–	–	–	8.7E+2
Krypton-88	1.5E+3	–	–	–	–	1.5E+3
Niobium-95	–	6.4E-2	–	–	–	6.4E-2
Plutonium-238	–	4.57E-3	–	–	–	4.6E-3
Plutonium-239(a)	4.4E-6	2.8E-3	3.6E-7	–	–	2.8E-3
Ruthenium-103	–	1.3E-2	–	–	–	1.3E-2
Ruthenium-106	–	7.8E-2	–	–	–	7.8E-2
Strontium-90(b)	4.5E-4	3.1E-3	–	–	5.0E-6	3.5E-3
Uranium-234	–	6.1E-3	–	–	–	6.1E-3
Uranium-238	–	6.1E-3	–	–	–	6.1E-3
Xenon-131m	–	6.4	–	–	–	6.4
Xenon-133	3.9E+3	–	–	–	–	3.9E+3
Xenon-135	2.5E+3	–	–	–	–	2.5E+3
Zirconium-95	–	1.7E-2	–	–	–	1.7E-2

(a) Includes one-half that activity designated as "Unidentified Alpha."

(b) Includes one-half that activity designated as "Unidentified Beta + Gamma."

Table 2.13-2. Radionuclide emissions from the Savannah River Plant, 1979 to 1981 (Ci/y)

Radionuclide	1979	1980	1981
Americium-241(a)	4.1E-4	1.1E-3	5.0E-4
Argon-41	5.3E+4	7.0E+4	6.2E+4
Carbon-14	5.6E+1	6.6E+1	6.9E+1
Cerium-141	1.6E-4	1.1E-4	3.2E-4
Cerium-144	1.8E-2	1.6E-2	2.6E-2
Curium-244	3.9E-4	9.0E-4	1.6E-4
Cobalt-60	4.0E-4	6.2E-4	8.9E-5
Cesium-134	2.7E-2	3.8E-4	6.4E-4
Cesium-137	2.7E-3	2.6E-3	3.1E-3
Tritium	3.1E+5	2.9E+5	3.5E+5
Iodine-129(b)	1.3E-1	1.6E-1	1.6E-1
Iodine-131	8.4E-2	2.1E-2	4.7E-2
Krypton-85	4.8E+5	5.8E+5	8.4E+5
Krypton-85m	1.8E+3	3.2E+3	1.3E+3
Krypton-87	1.5E+3	2.8E+3	8.7E+2
Krypton-88	2.3E+3	4.0E+3	1.5E+3
Niobium-95	2.6E-2	1.8E-2	6.4E-2
Plutonium-238	1.4E-3	2.8E-3	4.6E-3
Plutonium-239(a)	4.5E-4	1.3E-3	2.8E-3
Ruthenium-103	4.8E-3	1.7E-3	1.3E-2
Ruthenium-106	5.5E-2	6.0E-2	7.8E-2
Strontium-90(b)	2.6E-3	3.6E-3	3.5E-3
Uranium-234	2.4E-3	4.0E-3	6.1E-3
Uranium-238	2.4E-3	4.0E-3	6.1E-3
Xenon-131m	9.1	1.9E-1	6.4
Xenon-133	5.3E+3	4.9E+3	3.9E+3
Xenon-135	4.5E+3	6.4E+3	2.5E+3
Zirconium-95	1.3E-2	1.4E-2	1.7E-2

(a) Includes one-half that activity designated as "Unidentified Alpha."
(b) Includes one-half that activity designated as "Unidentified Beta + Gamma."

2.13.4 Health Impact Assessment of Savannah River Plant

The estimated annual radiation doses and fatal cancer risks resulting from radionuclide emissions in 1981 from the Savannah River Plant are listed in Tables 2.13-3 and 2.13-4. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I. The nearby individuals are located 10,500 m east of the assumed release location (center of site). The predominant exposure pathway is that of ingestion. The doses are primarily from tritium and argon-41.

Table 2.13-3. Radiation dose rates from radionuclide emissions from the Savannah River Plant, 1981

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Thyroid	4.9	1.2E+2
Endosteum	2.3	1.0E+2
Pulmonary	2.2	1.0E+2

Table 2.13-4. Fatal cancer risks due to radioactive emissions from the Savannah River Plant, 1981[a]

Source	Lifetime risk to nearby individuals		Regional population (Fatal cancers/y of operation)	
SRP	4E-5	(2E-5)	3E-2	(1E-2)

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

2.14 Ames Laboratory; Ames, Iowa

2.14.1 General Description

Ames Laboratory is operated by Iowa State University for the Department of Energy. The principal facility is the Ames Laboratory Research Reactor, located 2.4 km northwest of the Iowa State University campus and 4.8 km northwest of Ames, Iowa. The site occupies 16.2 hectares in Story County.

2.14.2 Description of Facility

The Ames Laboratory Research Reactor (ALRR) was used until 1978 as a neutron source for the production of byproduct materials and the neutron irradiation of various materials for research. The reactor was fueled with enriched uranium, was moderated and cooled by heavy water (D_2O), and was operated continuously at 5000 watts thermal. Operation of the ALRR was terminated on December 1, 1977. Decommissioning began January 3, 1978, and was completed on October 31, 1981. At present, varied research programs involving small amounts of radionuclides are carried out at the site.

2.14.3 Radionuclide Emissions

Prior to decommissioning, the major airborne releases were tritium and argon-41 from the ALRR. Tritium was the major radionuclide released during the 1981 decommissioning activities. Table 2.14-1 contains the release data for 1981. These releases are from the 30-meter reactor stack, located 215 meters from the nearest boundary, with an annual exhaust volume of 2.5E+14 ml. No airborne emissions have been found from the research laboratories on the main campus.

2.14.4 Health Impact Assessment of Ames Laboratory

The estimated annual radiation doses and fatal cancer risks from radionuclide emissions from ALRR are listed in Tables 2.14-2 and 2.14-3. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I. These estimates are based on a regional population of 630,000. The nearby individuals are located 750 meters north of the facility. The major pathway of exposure was ingestion.

Table 2.14-1. Radionuclide emissions from Ames Laboratory, 1981

Radionuclide	Emissions (Ci/y)
Cobalt-60	2.2E-7
Tritium	4.5
Unidentified alpha	1.6E-7
Unidentified beta + gamma	2.7E-6
Zinc-65	2.4E-7

Table 2.14-2. Radiation dose rates from radionuclide emissions from Ames Laboratory for 1981

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Endosteum	1.1E-3	4.8E-3
Pulmonary	9.6E-4	4.0E-3

Table 2.14-3. Fatal cancer risks due to radionuclide emissions from Ames Laboratory, 1981[a]

Source	Lifetime risk to nearby individuals	Regional population (Fatal cancers/y of operation)
ALRR Stack	2E-8 (7E-9)	1E-6 (4E-7)

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8 Volume I, of this report.

2.15 Bettis Atomic Power Laboratory; West Mifflin, Pennsylvania

2.15.1 General Description

The Bettis Atomic Power Laboratory is operated for the Department of Energy by the Westinghouse Electric Company. It is sited on an 0.8 square kilometer tract in West Mifflin, Pennsylvania, approximately 12 km southeast of Pittsburgh. The facility designs and develops nuclear reactors for the DOE Naval Reactors Program. The population within 80 kilometers of the site is 3.2 million.

2.15.2 Description of Facility

Bettis facilities, which include both development laboratories and fabrication facilities, are clustered in the northwest corner of the site. There is no information available which identifies the activities conducted within specific buildings at the site. Emissions data for the site are reported only in aggregate form; therefore, it is impossible to attribute releases to a specific activity.

2.15.3 Radionuclide Emissions and Existing Control Technology

Airborne emissions data for Bettis are presented in Table 2.15-1. Reported airborne releases are primarily krypton-85, with much lesser amounts of antimony-125 and iodine-131.

Gaseous effluent streams from activities at Bettis are treated with wet scrubbing and passed through charcoal absorbers and HEPA filtration units prior to release.

Table 2.15-1. Radionuclide emissions from
Bettis Atomic Power Laboratory, 1981

Radionuclide	Emissions (Ci/y)
Tritium	3.0E-5
Iodine-129	2.5E-7
Iodine-131	8.4E-7
Krypton-85	1.6E-1
Antimony-125	5.8E-5
Unidentified alpha (assumed equally uranium-234 and uranium-238)	1.8E-6
Unidentified beta-gamma (assumed equally cesium-137, cobalt-60, and strontium-90)	1.52E-5

2.15.4 Health Impact Assessment of Bettis Atomic Power Laboratory

The entire site is modeled as a ground level point source located centrally within the facility. For purposes of the dose/health effects assessment, it is assumed that all particulates released are respirable. Actual site boundary distances were used for the location of the nearby individuals.

Table 2.15-2 lists the estimates of the annual radiation doses resulting from radionuclide emissions. The nearby individuals are located 410 meters north of the release point. The major pathway contributing to the individual dose equivalent rate is inhalation.

Table 2.15-3 lists estimates of the lifetime risk to nearby individuals and the number of fatal cancers to the regional population from these doses. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I. Inhalation is the predominant pathway contributing to the fatal cancer risk.

Table 2.15-2. Radiation dose rates from radionuclide emissions from the Bettis Atomic Power Laboratory

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Pulmonary	3.9E-3	3.8E-2
Thyroid	1.5E-3	3.2E-3
Endosteum	8.6E-4	4.9E-3
Red marrow	5.5E-4	3.9E-3

Table 2.15-3. Fatal cancer risks due to radionuclide emissions from the Bettis Atomic Power Laboratory[a]

Source	Lifetime risk to nearby individuals	Regional population (Fatal cancers/y of operation)
BAPL	1E-8 (8E-9)	2E-6 (1E-6)

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

2.16 Knolls Atomic Power Laboratory; Knolls, Kesselring, and Windsor Sites; Schenectady, New York

2.16.1 General Description

The Knolls Atomic Power Laboratory (KAPL) is operated for the Department of Energy by the General Electric Company. The facilities of KAPL are located on three separate sites: Knolls, Kesselring, and Windsor. KAPL is one of the two laboratories operated for the DOE Naval Reactors Program.

Knolls and Kesselring Sites

The Knolls and Kesselring sites are both located in east central New York State. The Knolls facilities are located on a 0.69 square kilometer tract about 3.2 kilometers east of Schenectady. The Kesselring site is about 27 kilometers north of Schenectady, and occupies an area of almost 16 square kilometers. Schenectady, Albany, and Troy to the south, and Saratoga Springs to the north-northeast are the major population centers in the vicinity. Land use in the vicinity of the two sites is typical low density residential, with numerous small truck and dairy farms. The population within 80 kilometers is 1.2 million.

Windsor Site

The Windsor site, which occupies a 0.04 square kilometer tract, is located just northwest of the town of Windsor, Connecticut. Hartford, lying 8 kilometers south, and Springfield, Massachusetts, 20 kilometers north, are the major population centers in the vicinity of the facility. Land in the immediate area (0-10 km) is a mixture of low density residential and small scale agriculture. The principal crop is shade-grown wrapper tobacco. Population within 80 kilometers of the site is 3.1 million.

2.16.2 Description of Facility

Facilities at the Knolls site are utilized in the development of naval reactors. Nuclear power plant operators are trained at the Kesselring and Windsor sites. Pressurized water reactors are located at both the Kesselring and Windsor site.

2.16.3 Radionuclide Emissions and Existing Control Technology

The chemistry, physics, and metallurgy laboratories at the Knolls site are the only potential emitters of radionuclides to the atmosphere, while effluents from reactor operations are the only source of radioactive emissions at the Kesselring and Windsor sites.

All releases at the Knolls site are from elevated stacks (assumed height, 20 meters) and all exhaust streams carrying radioactive effluents are passed through HEPA filters or activated charcoal filters.

The exhaust systems of the reactors at both the Kesselring and Windsor sites are fitted with HEPA filtration systems to control particulate emissions. There are no controls for gaseous effluents. Releases at both sites are from elevated stacks.

Combined airborne emissions for 1981 from the KAPL sites are given in Table 2.16-1.

Table 2.16-1. Radionuclide emissions from Knolls Atomic Power Laboratory, 1981

Radionuclide	Emissions (Ci/y) Knolls and Kesselring sites	Windsor site
Argon-41	3.8	1.0E-4
Bromine-82	3.3E-4	
Carbon-14	1.8E-1	5.7E-3
Cobalt-60	2.3E-6	4.0E-7
Cesium-137	4.0E-5	
Iodine-131	4.05E-6	
Krypton-83m	1.1E-3	2.4E-4
Krypton-85	1.4E-1	1.0E-5
Krypton-85m	3.7E-3	8.5E-4
Krypton-87	3.4E-3	5.9E-4
Krypton-88	7.8E-3	1.6E-3
Manganese-54	2.3E-6	
Plutonium-239	1.7E-8	
Sulfur-35	1.8E-6	
Antimony-125	9.1E-6	
Strontium-90	4.0E-5	
Uranium-234	2.9E-5	
Uranium-235	8.7E-7	
Uranium-236	5.7E-8	
Uranium-238	9.0E-10	
Xenon-131m	2.5E-4	5.4E-5
Xenon-133m	1.4E-3	3.7E-4
Xenon-133	4.2E-2	1.0E-2
Xenon-135	4.0E-2	9.5E-3
Xenon-138	1.3E-3	

2.16.4 Health Impact Assessment of KAPL

All airborne particles released are assumed to be respirable. The assessment is based on all releases for the Knolls and Kesselring sites being combined at a central point at the Knolls site. A release height of 10 meters was assumed for all effluents. Actual site boundary distances were used for the Knolls site and the Windsor site. Table 2.16-2 presents the dose rates from radionuclide emissions at these sites.

Knolls and Kesselring Sites

For the Knolls and Kesselring sites, the nearby individuals are located 300 meters north of the release point. Ingestion is the major pathway of exposure.

Windsor Site

For the Windsor site, the nearby individuals are located 110 m south of the release point. Inhalation is the major pathway of exposure.

Table 2.16-2. Radiation dose rates from radionuclide emissions from the Knolls and Kesselring Sites

Organ	Nearby individuals (mrem/y)	
	Knolls and Kesselring sites	Windsor site
Endosteum	1.4E-1	6.6E-3
Red marrow	7.8E-2	3.6E-3
Breast	5.0E-2	2.4E-3
Pulmonary	4.7E-2	1.5E-3
	Regional population (person-rem/y)	
	Knolls and Kesselring sites	Windsor site
Endosteum	2.3E-1	2.8E-3
Red marrow	1.4E-1	1.7E-3
Breast	1.0E-1	1.3E-3
Pulmonary	1.3E-1	9.6E-4

The lifetime risk to the nearby individuals and the total number of fatal cancers per year of operation of these sites are listed in Table 2.16-3. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I. Air immersion is the major pathway of exposure for these estimates.

Table 2.16-3. Fatal cancer risks due to radionuclide emissions from Knolls Atomic Power Laboratory[a]

Source	Lifetime risk to nearby individuals		Regional population (Fatal cancers/y of operation)	
Knolls and Kesselring sites	9E-7	(4E-7)	3E-5	(1E-5)
Windsor site	4E-8	(2E-8)	3E-7	(1E-7)

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

2.17 Lawrence Berkeley Laboratory; Berkeley, California

2.17.1 General Description

Lawrence Berkeley Laboratory (LBL) is operated for the Department of Energy by the University of California-Berkeley. The Laboratory is located in the Berkeley Hills, above the University of California-Berkeley campus. The site is three kilometers from downtown Berkeley, about 20 kilometers from downtown Oakland, and 30 kilometers from downtown San Francisco. The population within a 50-mile radius of the Laboratory is 4.5 million. This includes most of the residents of the greater metropolitan San Francisco Bay area.

Lawrence Berkeley Laboratory is a large multifaceted research laboratory conducting programs of pure and applied research in physical, biological, and environmental sciences.

2.17.2 Description of Facility

LBL research facilities include four large accelerators, several small accelerators, a number of radiochemical laboratories, and a tritium labeling laboratory. The large accelerators include the Bevatron, the Super HILAC, the 224-centimeter Sector-Focused Cyclotron, and the 467 centimeter Cyclotron.

The Tritium Facility was designed to accommodate kilocurie quantities of tritium as a labeling agent for chemical and biomedical research. Radiochemical and radiobiological studies in many laboratories typically use millicurie quantities of various radionuclides.

2.17.3 Radionuclide Emissions

Radionuclide emissions during 1981 at Lawrence Berkeley Laboratory are shown in Table 2.17-1.

Table 2.17-1. Radionuclide emissions from Lawrence Berkeley Laboratory, 1981

Radionuclide	Emissions (Ci/y)
Carbon-14	3.6E-2
Cobalt-60	4.0E-5
Tritium	70.4
Iodine-125	5.7E-4
Plutonium-239	2.5E-9
Strontium-90	4.0E-5

2.17.4 Health Impact Assessment of Lawrence Berkeley Laboratory

Table 2.17-2 lists the estimates of the annual radiation doses resulting from radionuclide emissions. The nearby individuals are located 100 meters east of the assumed release point. The predominant exposure pathway is ingestion.

Table 2.17-3 gives the estimates of the lifetime risk to nearby individuals and the number of fatal cancers per year of operation. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I. Ingestion is the major pathway for population exposure.

Table 2.17-2. Radiation dose rates from radionuclide emissions from the Lawrence Berkeley Laboratory

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Thyroid	1.6	7.7E-1

Table 2.17-3. Fatal cancer risks due to radionuclide emissions from the Lawrence Berkeley Laboratory[a]

Source	Lifetime risk to nearby individuals		Regional population (Fatal cancers/y of operation)	
LBL	9E-6	(4E-6)	2E-4	(8E-5)

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

2.18 Mound Facility; Miamisburg, Ohio

2.18.1 General Description

Mound Facility is located in Miamisburg, Ohio, approximately 16 kilometers southwest of Dayton. Mound Facility has extensive programs in research and development (R&D), recovery and handling of tritium from solid waste, and development, fabrication, and testing of weapons components for the Department of Defense (DOD). Specific programs in these areas include the separation, purification, and sale of stable isotopes of noble gases and fabrication of chemical and radioisotopic heat sources for space and military applications.

2.18.2 Description of Facility

Nine buildings at the Mound Facility released radioactivity into the atmosphere in 1981. Operations at these facilities resulted in the release of tritium and plutonium-238.

Tritium was released in atmospheric effluents from the HH and SW Buildings. Operations at the HH Building involve the recovery of helium-3 which is contaminated with tritium. Gaseous wastes generated there are stored and transferred to the SW Building. At the SW Building, operations involve disassembly, analysis and development of nuclear components containing tritium, and the recovery of tritium wastes.

Plutonium-238 was released in airborne effluents from H, PP, R, SM, WD, WDA, and 41 Buildings. Contaminated clothing is laundered at the H Building. Plutonium processing and other related activities are conducted at the PP Building. At the R Building plutonium heat source production is the principal activity. The SM Building is an idle contaminated facility. Operations at the WD, WDA, and 41 Buildings involve radioactive waste disposal processes.

2.18.3 Radionuclide Emissions and Existing Control Technology

Table 2.18-1 identifies radioactive emissions from nine buildings at the Mound Facility in 1981.

Total emissions are assumed to be released from the SW Building with an effective stack height of 61 meters. Table 2.18-2 compares the radioactive emissions from Mound for the years 1979 to 1981.

Tritium in gaseous effluents streams of the SW building are treated before release by the effluent removal system, which oxidizes elemental tritium and then removes the resulting tritiated water by molecular sieve drying beds. At all other facilities, particulate radioactivity is removed from process air streams by HEPA filters.

Table 2.18-1. Radionuclide emissions from the Mound Facility, 1981

Source	Emissions (Ci/y)	
	Tritium	Plutonium-238
H Building stack		1.1E-10
HH Building stack	5.26E+1	
PP Building stack		1.21E-6
R Building stack		3.55E-7
SM Building stack		6.49E-6
SW Building		
SW stack	6.13E+2	
NCDPF stack	3.80E+2	
HEFS stack	3.24E+3	
WD Building		
WD sludge solidification stack		4.20E-8
WDA low risk stack		4.14E-8
WDA Building		
WDA low risk stack		1.07E-7
WDA high risk stack		2.50E-8
Building 41 stack	———	2.31E-9
Total curie release	4.29E+3	8.28E-6

Table 2.18-2. Radionuclide emissions from the Mound Facility, 1979 to 1981 (Ci/y)

Radionuclide	1979	1980	1981
Tritium	3.83E+3	3.80E+3	4.29E+3
Plutonium-238	1.17E-5	1.52E-5	8.28E-6

2.18.4 Health Impact Assessment of the Mound Facility

The estimated annual radiation doses resulting from radionuclide emissions in 1981 from the Mound Facility are listed in Table 2.18-3. The nearby individuals are located 1,500 meters north-northeast of the assumed release point (SW Building). Ingestion is the major pathway of exposure, and nearly all of the dose is attributable to tritium.

Table 2.18-4 gives the estimates of the lifetime risk to nearby individuals and the number of fatal cancers to the regional population from these doses. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I. The regional population within an 80 kilometer radius of the site is 2.9 million. Ingestion is the major pathway for population exposure.

Table 2.18-3. Radiation dose rates from radionuclide emissions from the Mound Facility, 1981

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Intestine wall	2.5E-1	11.4
Endosteum	1.5E-1	7.1
Kidneys	1.9E-1	9.0

Table 2.18-4. Fatal cancer risks due to radionuclide emissions from the Mound Facility, 1981[a]

Source	Lifetime risk to nearby individuals	Regional population (Fatal cancers/y of operation)
Mound Facility	4E-6 (1E-6)	3E-3 (1E-3)

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

2.19 Nevada Test Site; Nye County, Nevada

2.19.1 General Description

The Nevada Test Site (NTS) is located in Nye County, Nevada. The site is approximately 100 kilometers northwest of Las Vegas and covers an area of about 3,500 square kilometers.

NTS is part of DOE's nuclear weapons research and development complex. Programs at NTS include nuclear weapons development, proof testing and weapons safety, nuclear physics programs, and studies of high-level waste management. Primary activities at NTS are centered around the testing of weapons. Tests are conducted at the site for DOE contractors (e.g., Lawrence Livermore Laboratories, Los Alamos Scientific Laboratory, Reynolds Electrical Engineering, and for the Department of Defense). Since 1962, all nuclear weapons tests have been conducted underground.

2.19.2 Description of Facility

The Nevada Test Site is divided into six operational areas. Non-weapons programs are conducted in Area 27 and at the NTS experimental test farm. Support facilities for most NTS activities are found in the Mercury vicinity. Underground test sites include Mesa vicinity (the NTS experimental farm is also located in this area) and Pahute Mesa vicinity (used for higher yield underground tests).

2.19.3 Radionuclide Emissions and Existing Control Technology

Radionuclides are released primarily from underground test sites. Activities responsible for these releases are conducted after underground nuclear detonations and include re-entry drilling operations and tunnel ventilations.

Reported releases for drill-back operations and tunnel ventilations are presented in Table 2.19-1. In addition to the monitored releases, the source terms from NTS should include the continuing release (due to leakage) of krypton and tritium. These releases have not been measured but are estimated to be several hundred curies per year. Plutonium also contributes to the source term because of resuspension of soil from contaminated areas, but there are no data quantifying such emissions. Experiments with waste disposal and fuel storage may possibly release radionuclides, but no releases have been reported for these operations.

During drill-back operations and tunnel ventilations, emissions are controlled by passing the air streams through HEPA filters to control particulates and through charcoal absorbers to control radioiodine. There are no applicable controls for the continued leakage of noble gases and tritium. Although it is possible to reduce the quantities of plutonium in contaminated areas, these areas are being used for research into the behavior of plutonium in the environment.

Table 2.19-1. Radionuclide emissions from Nevada Test Site in 1981

Radionuclide	Emissions (Ci/y)
Tritium	534
Iodine-131	0.05
Xenon-133	2700
Xenon-133m	29
Xenon-135	142

2.19.4 Health Impact Assessment of the Nevada Test Site

The estimated annual individual radiation dose equivalents from radionuclide emissions from the Nevada Test Site are shown in Table 2.19-2. The nearby individuals are located 34,000 meters south of the assumed release point located near the center of the test site. Air immersion is the major pathway for the individual dose equivalent rate.

Table 2.19-3 lists the estimates of the lifetime risk to nearby individuals and the number of fatal cancers to the regional population. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I. Ingestion is the major pathway contributing to the fatal cancer risk.

Table 2.19-2. Radiation dose rates from radionuclide emissions from the Nevada Test Site

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Red marrow	2.1E-3	1.1E-3
Thyroid	1.8E-3	2.1E-3

Table 2.19-3. Fatal cancer risks due to radioactive emissions from the the Nevada Test Site[a]

Source	Lifetime risk to nearby individuals		Regional population (Fatal cancers/y of operation)	
NTS	3E-8	(1E-8)	3E-7	(1E-7)

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

2.20 Pantex Plant; Amarillo, Texas

2.20.1 General Description

The Pantex Plant is operated for the Department of Energy (DOE) by Mason & Hanger - Silas Mason Company, Inc. Pantex is a weapons testing and surveillance facility. Primary objectives of the plant include:

- fabrication and test firing of chemical high explosives,
- assembly of nuclear weapons,
- surveillance of atomic weapon stockpiles, and
- retirement of atomic weapons.

The Pantex Plant is situated on a 37 square kilometer site in the Texas panhandle, approximately 27 kilometers northeast of Amarillo, Texas.

The Pantex Plant is split into numerous zones and some zones are only 250 meters from the boundary. Land in the vicinity of Pantex is almost exclusively rural, with agricultural activities having the most significant impact on the area economy. Principal crops are wheat and grain sorghums. Cattle ranching and feeding are also of importance. There is almost no industry in the area.

The population within 80 kilometers of Pantex is approximately 259,000. This includes Amarillo, located 30 kilometers to the southwest with a population of 150,000, and Pampa, 65 kilometers to the northeast with a population of 23,000.

2.20.2 Description of Facility

The primary mission at Pantex involves assembling, monitoring, and retiring atomic weapons. Significant quantities of plutonium, uranium, and tritium are handled during these activities. However, with few exceptions, these materials are handled only in sealed containers which are not opened at the site. Therefore, normal emissions at Pantex are limited, although the potential for an accident involving significant releases does exist.

Pantex conducts explosive test fires of chemical high explosives as a regular part of its operations. These test fires occur on an irregular basis, and vary in number from year to year. In recent years, all such tests were conducted at Firing Site 5, and the only radioactive material released was depleted uranium-238.

2.20.3 Radionuclide Emissions and Existing Control Technology

Airborne emissions from Pantex for 1981 are given in Table 2.20-1. Tritium is emitted from the Assembly Area, and depleted uranium is the only radionuclide released from activities at Firing Site 5. The emissions for 1979 and 1980 are also summarized in Table 2.20-1.

Reports issued by Pantex indicate that no control technology is being used in the assembly areas since all radioactive materials are handled in sealed containers. No control technologies are appropriate to the releases which result from the test firings, so atmospheric dilution is relied upon.

Table 2.20-1. Radionuclide emissions from Pantex Plant 1979 to 1981 (Ci/y)

Radionuclide	1979	1980	1981
Tritium	2.0E-2	1.0E-1	9.5E-2
Uranium-238	3.0E-5	5.0E-5	1.0E-5

2.20.4 Health Impact Assessment for the Pantex Plant

For the purposes of dose/health effects assessment, it is assumed that all particles released are respirable. The assessment is based on all emissions in 1981 being combined into one central point on the site. Actual site boundary distances were used in the calculations.

The estimated annual radiation doses resulting from radionuclide emissions in 1981 from the Pantex Plant are listed in Table 2.20-2. The nearby individuals are located 1,350 meters north of the release point. The major pathway contributing to the individual dose equivalent rate is inhalation.

Table 2.20-3 gives the estimates of the lifetime risk to nearby individuals and the number of fatal cancers to the regional population. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I. The pathway contributing primarily to the fatal cancer risk is inhalation.

Table 2.20-2. Radiation dose rates from radionuclide emissions from the Pantex Plant, 1981

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Pulmonary	4.6E-3	2.6E-3
Kidneys	3.9E-5	3.9E-5

Table 2.20-3. Fatal cancer risks due to radionuclide emissions from the Pantex Plant, 1981[a]

Source	Lifetime risk to nearby individuals	Regional population (Fatal cancers/y of operation)
Pantex Plant	8E-9 (7E-9)	7E-8 (6E-8)

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

2.21 Pinellas Plant; Pinellas County, Florida

2.21.1 General Description

The Pinellas Plant is operated by the Neutron Devices Department of the General Electric Company. The plant is located on a 39-hectare site in the center of Pinellas County, Florida, approximately 10 kilometers northwest of St. Petersburg. Pinellas is an integral part of the nation's weapons program. Major operations include the design, development, and manufacture of special electronic and mechanical nuclear weapons components. The population within 80 km is approximately 1.9 million.

2.21.2 Description of Facility

The principal operations causing atmospheric releases of radioactive materials are not described in the literature. However, they involve neutron generator development and production, testing, and laboratory operations.

Small sealed plutonium capsules are used as heat sources in the manufacture of radioisotopic thermoelectric generators at Pinellas Plant. These sources are triply encapsulated so as to prevent release of plutonium to the atmosphere.

2.21.3 Radionuclide Emissions and Existing Control Technology

The principal releases of radioactivity reported are tritium gas, tritium oxide, krypton-85, and carbon-14. Locations and quantities of releases reported are given in Table 2.21-1.

Areas utilizing radioactive materials are connected to a special exhaust system which is designed to trap tritium and reduce the amount released to the atmosphere. In this system tritium gas is converted to the oxide form by passage through heated copper oxide beds. Then the tritiated water vapor is absorbed by silica gel.

Table 2.21-1. Radionuclide emissions from Pinellas Plant, 1981

Radionuclide	Emissions (Ci/y)		
	Main Stack	Laboratory Stack	Building 800
Tritium gas	129.2	89.7	2.81
Tritium oxide	115.3	75.4	4.63
Krypton-85	3.7	--	--
Carbon-14	--	8.5E-5	--

2.21.4 Health Impact Assessment of Pinellas Plant

The estimated annual individual radiation dose equivalents from radionuclide emissions from the Pinellas Plant are shown in Table 2.21-2. The nearby individuals are located 470 meters west of the release point. Ingestion is the major contributor to the individual dose equivalent rate.

The risks of fatal cancer are shown in Table 2.21-3. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I. The inhalation pathway contributes most of the fatal cancer risk.

Table 2.21-2. Radiation dose rates from radionuclide emissions from the Pinellas Plant

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Kidneys	2.5E-1	8.9E-1
Intestine wall	3.0E-1	1.1

Table 2.21-3. Fatal cancer risks due to radioactive emissions from the Pinellas Plant[(a)]

Source	Lifetime risk to nearby individuals		Regional population (Fatal cancers/y of operation)	
Pinellas Plant	5E-6	(2E-6)	2E-4	(1E-4)

(a) The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

2.22 Rockwell International; Santa Susana, California

2.22.1 General Description

Rockwell International, a division of Rockwell International Corporation, has two nuclear energy research and development sites in the Los Angeles area. Current programs at these two facilities include the fabrication of test reactor fuel, decontamination, and the design, production, and testing of components and systems for central station power plants.

Canoga Park, the headquarters site, is approximately 37 kilometers northwest of downtown Los Angeles. Facilities at Canoga Park are used for administrative activities and for NRC- and State-licensed programs. The Santa Susana site (SSFL) is situated in the Simi Hills of Ventura County, approximately 48 kilometers northwest of Los Angeles. Facilities owned by the Department of Energy (DOE), as well as Rockwell-owned NRC- and State-licensed facilities, are located at SSFL.

2.22.2 Description of Facility

NRC- and State-licensed activities at Canoga Park include uranium fuel production (Building 001), research in analytical chemistry (Building 004), and cobalt-60 gamma irradiation studies. Non-DOE facilities at the Santa Susana site include the Rockwell International Hot Laboratory (RIHL) (Building 020), the Nuclear Materials Development Facility (NMDF) (Building 055), a neutron radiography facility containing the L-85 nuclear examination and research reactor (Building 093), and several X-radiography inspection facilities.

DOE operations at the Santa Susana site that release radioactive materials into the atmosphere are conducted at the Radioactive Material Disposal Facility (RMDF). The two buildings (021-022) that constitute this facility are used for processing wastes generated by a program for the decontamination and disposition of DOE facilities.

2.22.3 Radionuclide Emissions and Existing Control Technology

Table 2.22-1 compares radioactive releases for the years 1979-1981. The 1981 release information is used in the health impact assessment section.

HEPA filters are used to remove particulates from the effluent from the Radioactive Material Disposal Facility.

The total emissions are assumed to originate from Buildings 21 and 22, with an effective stack height of 30 meters.

Table 2.22-1. Radionuclide emissions from the SSFL (DOE facilities only), 1979 to 1981 (Ci/y)

Radionuclide	1979	1980	1981
MFP[(a)]	2.8E-6	1.8E-6	4.1E-6

(a) Mixed fission products; assumed to be strontium-90 for health impact assessment.

2.22.4 Health Impact Assessment of Rockwell International

The estimated annual radiation doses resulting from radionuclide emissions in 1981 from the DOE facilities at Santa Susana are listed in Table 2.22-2. The nearby individuals are located 180 meters north of the assumed release point (Buildings 21 and 22). Ingestion is the predominant exposure pathway.

Table 2.22-3 gives the estimates of the lifetime risk to nearby individuals and the number of fatal cancers per year of operation. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I. Ingestion is the primary pathway for population exposure. The regional population within 80 kilometers of the site is 8 million.

Table 2.22-2. Radiation dose rates from radionuclide emissions from the Rockwell International Plant, SSFL, 1981

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Endosteum	4.1E-5	1.2E-3
Red marrow	2.1E-5	5.8E-4
Thyroid	2.8E-7	7.9E-6

Table 2.22-3. Fatal cancer risks due to radionuclide emissions from the Rockwell International Plant, SSFL, 1981[a]

Source	Lifetime risk to nearby individuals		Regional population (Fatal cancers/y of operation)	
Rockwell	6E-11	(2E-11)	2E-8	(9E-9)

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

2.23 Sandia National Laboratories; Albuquerque, New Mexico

2.23.1 General Description

Sandia National Laboratories (SNL) is a nuclear ordnance laboratory with locations in Albuquerque, New Mexico, and Livermore, California. The Livermore site is discussed in Section 2.7 under the discussion of the Lawrence Livermore Laboratory. Sandia Laboratories serves as an interface between the nuclear weapons developed at the Los Alamos and Livermore Laboratories and military delivery systems. The Sandia site is located within the limits of Kirkland Air Force Base, 10 kilometers south of Albuquerque. Facilities at Albuquerque are grouped in five Technical Areas (TAs).

2.23.2 Description of Facility

The operations at SNL involve testing weapons for quality assurance and safeguards, arming, and fusing nuclear weapons, and developing modifications to delivery systems. The major facilities include two Sandia Pulsed Reactors and the Annular Core Research Reactor, which are used to irradiate test materials, and the Relativistic Electron Beam Accelerator. Support facilities include the Neutron Generator Facility, the Tube Loading Facility, the Fusion Target Loading Facility, the Tritium Laboratory, and the Nondestructive Test Facility. These facilities are located at Technical Areas I and V. TA-I, located in the northwest corner of the site, also houses research and design laboratories. TA-III is the location for the Sandia low-level radioactive waste storage site.

2.23.3 Radionuclide Emissions and Existing Control Technology

Airborne releases from operations at SNL, Albuquerque, are summarized in Table 2.23-1.

Table 2.23-1. Radionuclide emissions from Sandia National Laboratories, 1981

Radionuclide	Emissions (Ci/y)
Argon-41	6.84

2.23.4 Health Impact Assessment of Sandia National Laboratories

The entire site is treated as a single ground level point source release located centrally within the facility. Actual site boundary distances were used in the calculations.

Tables 2.23-2 and 2.23-3 list the estimated annual radiation doses and fatal cancer risks from radionuclide emissions from Sandia National Laboratories at Albuquerque. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I. The nearby individuals are located 3200 meters west-northwest of the source. Air immersion contributes essentially all of the observed dose equivalent rate and fatal cancer risk.

Table 2.23-2. Radiation dose rates from radionuclide emissions Sandia National Laboratories

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Endosteum	8.5E-4	3.6E-3
Breast	8.1E-4	3.4E-3
Red marrow	8.0E-4	3.4E-3

Table 2.23-3. Fatal cancer risks due to radionuclide emissions from Sandia National Laboratories[a]

Source	Lifetime risk to nearby individuals		Regional population (Fatal cancers/y of operation)	
SNL	1E-8	(6E-9)	9E-7	(4E-7)

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

2.24 Stanford Linear Accelerator Center; Stanford, California

2.24.1 General Description

The Stanford Linear Accelerator (SLAC) is located in the San Francisco Bay Area roughly halfway between San Francisco and San Jose. The total length of the accelerator and the experimental area is approximately 4.8 kilometers, oriented almost east-west, on about 1.7 square kilometers of Stanford University land. There are 4.2 million people living in the six counties of the San Francisco Bay Area.

SLAC is a large research laboratory devoted to theoretical and experimental research in high energy physics and to the development of new techniques in high energy accelerator particle detectors. The main tool of the laboratory is a linear accelerator which is used to accelerate electrons and positrons.

2.24.2 Description of Facility

The linear accelerator is approximately 3.2 kilometers long and produces beams of electrons with energies up to 31 billion electron volts (31 GeV). It can also accelerate positrons up to energies of 20 GeV. These beams can be used directly for experiments or they can be transported into either of two storage-ring facilities-SPEAR or PEP. These storage-rings are major laboratory facilities, roughly circular in shape, in which electrons and positrons brought from the accelerator are stored and circulated continuously in opposite directions. The energies are 4.5 and 18 GeV per beam for SPEAR and PEP, giving total collision energies of 9 and 36 GeV, respectively. SPEAR has been in operation since 1972 and PEP was first filled with beam on April 13, 1980.

With colliding beam storage rings, such as SPEAR and PEP, the beam particles are truly 'recycled'; the same particles are brought into collision over and over again, rather than striking a target only once. For this reason colliding beam devices produce much less radiation and residual radioactivity than do conventional accelerators.

2.24.3 Radionuclide Emissions and Existing Control Technology

Airborne radioactivity produced as a result of SLAC operations and respective half-lives of the radionuclides are listed in Table 2.24-1. During 1981, only 1.1 curies of gaseous radioactivity were released. For calculational purposes, the total release is assumed to be argon-41. No measurable particulate radioactivity was released.

SLAC does not routinely vent the facility while the beam is on. There is a waiting period to allow all isotopes, with the exception of argon-41, to decay before exhausting the facility. The release of radioactivity is, therefore, infrequent and limited to argon-41 for brief periods of 30 to 60 minutes.

If personnel entry must be made during an operating cycle, the facility is vented for 10 minutes prior to entry and after the primary beam has been shut off. This practice may result in the release of small quantities of radionuclides other than argon-41.

Table 2.24-1. Radionuclide half-lives and emissions from Stanford Linear Accelerator, 1981

Radionuclide	Half-life
Oxygen-15	2.1 minutes
Nitrogen-13	9.9 minutes
Carbon-11	20.5 minutes
Argon-41	1.8 hours
Total activity	1.1 curies

2.24.4 Health Impact Assessment of Stanford Linear Accelerator

The estimated annual radiation doses and fatal cancer risks resulting from radionuclide emissions from Stanford Linear Accelerator are listed in Tables 2.24-2 and 2.24-3. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I. The nearby individuals are located 250 meters south of the release location and the predominant exposure pathway is air immersion.

Table 2.24-2. Radiation dose rates from radionuclide emissions from Stanford Linear Accelerator

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Endosteum	5.6E-3	3.6E-2
Breast	5.3E-3	3.4E-2
Red Marrow	5.3E-3	3.4E-2

Table 2.24-3. Fatal cancer risk due to radionuclide emissions from Stanford Linear Accelerator(a)

Lifetime risk to nearby individuals	Regional population (Fatal cancers/y of operation)
1E-7 (4E-8)	9E-6 (4E-6)

(a)The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

2.25 Reactive Metals, Inc.; Ashtabula, Ohio

2.25.1 General Description

Reactive Metals, Inc. (RMI), is located in northeastern Ohio in the City and County of Ashtabula approximately 80 km northeast of Cleveland, 65 km north of Warren, and 80 km north of Youngstown, the closest major population centers. According to the 1970 U.S. Census, the population of Ashtabula County is 102,000 and the population within 80 km of the facility is about 1.6 million.

2.25.2 Process Description

Reactive Metals operates an extrusion plant which fabricates uranium rods and tubing from ingots for use as fuel elements in nuclear reactors. The ingots are first extruded by a press into either rods or tubing, cooled, and then sectioned by abrasive sawing. Scrap material is fed to a pyrophoric incinerator to form a uranium oxide.

Air from each stage of the fabrication process is exhausted through a separate stack. Stacks 1, 2, and 3 exhaust air from the extension press tunnel, the press exit area, and the cooling table area, respectively. Air from the abrasive saws is exhausted from Stack 4. The only stack with filtration, Stack 5, exhausts the incinerator. This stack has a Roto-Clone Type N Air Scrubber.

2.25.3 Radionuclide Emissions

The only radioactive material released to the air from RMI is insoluble natural uranium. Radionuclide emissions from Reactive Metals in 1981 are listed in Table 2.25-1.

2.25.4 Health Impact Assessment

To evaluate the health impact from the operation of RMI, releases from the facility were assumed to be from a single 10-meter stack. The released material was assumed to be equal quantities of uranium-234 and uranium-238 in equilibrium with daughters thorium-234 and protactinium-234m, all in an insoluble form.

The estimated annual radiation doses and fatal cancer risks resulting from emissions at RMI are listed in Tables 2.25-2 and 2.25-3. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I. These estimates are based on a regional population of 1.6 million. The nearby individuals are located 120 meters north of the release point. The critical organ is the pulmonary and the predominant exposure pathway is inhalation.

Table 2.25-1. Radionuclide emissions from Reactive Metals, Inc., 1981

Source	Radionuclide	Emissions (Ci/y)
Stack 1	Natural uranium	3.56E-4
Stack 2	Natural uranium	1.49E-4
Stack 3	Natural uranium	1.18E-3
Stack 4	Natural uranium	3.03E-3
Stack 5	Natural uranium	6.79E-5

Table 2.25-2. Radiation dose rates from radionuclide emissions from Reactive Metals, Inc., 1981

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Pulmonary	51.8	19.5
Endosteum	0.27	0.12
Kidneys	0.14	0.06
Intestinal wall	0.06	0.04

Table 2.25-3. Fatal cancer risks from radionuclide emissions from Reactive Metals, Inc., 1981(a)

Source	Lifetime risk to nearby individuals		Regional population (Fatal cancers/y of operation)	
RMI	8E-5	(8E-5)	4E-4	(4E-4)

(a)The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

2.26 Worldwide Impact of Selected Radionuclides

Some radionuclides released from a site may have worldwide health consequences from their dispersion in the biosphere and their relatively long half-life. The emissions of carbon-14, iodine-129 and krypton-85 from all Department of Energy sites were considered in this regard (Table 2.26-1).

Table 2.26-1. Emissions of selected radionuclides from DOE facilities which may lead to worldwide impact

Source[a]	Emissions (Ci/y)		
	Carbon-14	Iodine-129	Krypton-85
Argonne National Laboratory	0	0	6.7
Brookhaven National Laboratory	8.1E-4	0	0
Hanford Reservation	3.2	0	250
Idaho National Engineering Laboratory	1.7E-1	3.7E-2	5.9E+4
Oak Ridge Reservation	1.2E-3	0	6.6E+3
Savannah River Plant	6.9E+1	1.6E-1	8.4E+5
KAPL	1.8E-1	-	1.4E-1
LBL	3.6E-2	-	-
Pinellas	-	-	3.7
Shippingport	7.2E-2	-	-
Combined releases for all DOE facilities	7.2E+1	2.0E-1	9.0E+5

(a) DOE facility having significant releases of selected radionuclides.

Carbon-14

By combining the emission of 72 Ci per year and the dose equivalent conversion of 700 person-rem per Ci released, a worldwide dose equivalent of 50,400 person-rem were committed from 1981 emissions of carbon-14. Similarly, the estimate of fatal cancers due to these emissions (using 0.1 fatal cancers per Ci--Table 2.26-2) is 7. Those effects would be observed during the time it takes carbon-14 to decay away, or over approximately 40,000 years.

Table 2.26-2. Estimated radiation doses and fatal cancers from emissions of selected radionuclides from DOE facilities to the world population

Radionuclide	World population		
	(person-rem/Ci)	(Fatal cancers/Ci release)(a)	
Carbon-14	7E+2(b)	1E-1(c)	(4E-2)
Krypton-85	4E-3(d)	1E-6(e,f)	(4E-7)
Iodine-129	2.8E+5(g)	8E+1(f)	(3E+1)

(a) The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

(b) Dose equivalent recorded by red marrow and endosteal cells, (United Nations Scientific Committee on the Effects of Atomic Radiation, Sources and Effects of Ionizing Radiation, Annex C, 1977, p. 120).

(c) Health effects integrated over all time (Fowler T. W. and Nelson C. B., Health Impact Assessment of Carbon-14 Emissions from Normal Operations of Uranium Fuel Cycle Facilities, EPA 520/5-80-004, Office of Radiation Programs, Environmental Protection Agency, Washington, D.C., 1979).

(d) Dose equivalent is received by the skin (UNSCEAR, Sources and Effects of Ionizing Radiation, Annex C, 1977, p. 121).

(e) National Council on Radiological Protection, Krypton-85 in the Atmosphere, Report No. 44, 1975.

(f) Assumed 200 fatal cancer per million person-rem received.

(g) Kocher, D. C., A Dynamic Model of the Global Iodine Cycle and Estimation of Dose to the World Population from Releases to the Environment, Environment International, Vol. 5, 15-31, 1981.

Iodine-129 and Krypton-85

The worldwide health impact of emissions of iodine-129 and krypton-85 are of similar concern. In 1981, 0.20 Ci of iodine-129 and 900,000 Ci of krypton-85 were released from operations at all DOE sites.

The committed collective dose equivalent due to iodine-129 was 56,000 person-rem; for krypton-85, 3600 person-rem.

Health effects conversion factors taken from Table 2.26-2 were used to calculate estimated fatal cancers committed over the entire environmental residence time of iodine-129 and krypton-85. For iodine-129 this was 16 fatal cancers and for the krypton-85 this yielded an estimated 0.9 fatal cancers. Both of these calculated values are based on an assumption of 280 fatal cancers per million person-rem received by the world population.

2.27 Future operations at DOE Facilities

2.27(A) Resumption of operations at the PUREX Plant

The U.S. Department of Energy has proposed the resumption of fuel reprocessing in the PUREX plant in the 200 area of the Hanford site. If the resumption occurs as scheduled, atmospheric releases will be significantly increased from their present value. For this reason, the risk from the expected atmospheric emissions has been calculated for operation of the PUREX plant in the 200 Area of the Hanford site.

Process Description

The PUREX process is based on dissolution, solvent-extraction, and ion-exchange and is used to recover uranium, plutonium, and neptunium from the N-Reactor's irradiated fuel elements. Wastes generated during the process are treated and returned to the process flow or shipped to the AR Vault for disposal. The PUREX Plant has been operated on an intermittent schedule, determined by national security needs and the production of the N-Reactor. The plant has been on standby since 1972, but a draft Environmental Impact Statement (DOE/EIS-0089D) indicates that PUREX will be reactivated in 1984 for additional reprocessing of N-Reactor fuel. The PUREX Plant was in operation for 17 years between 1950 and 1972 for separating plutonium from reactor fuel elements produced by the operating reactors in the 100 Area of Hanford.

The plant is expected to reprocess up to 3000 MT of N-Reactor fuel per year. Estimated releases from PUREX during the forthcoming operation have been estimated by DOE using experience gained during the previous operation as well as the effects of improved control technology which have been added since 1975. A summary of these estimated atmospheric releases is given in Table 2.27(A)-1.

Radionuclide Emissions and Existing Control Technology at Purex

Table 2.27(A)-1 gives the estimated airborne releases from PUREX plant assuming a fuel reprocessing rate of 3000 MT per year. Airborne effluents from all PUREX release points are passed through acid scrubbers, deentrainers, fiberglass filters, and HEPA filters prior to release. In addition, emissions from the PUREX plant are passed through a silver nitrate reactor to remove elemental iodine.

Health Impact Assessment from Operations at the PUREX Plant

The estimated radiation dose rates and fatal cancer risks from resumed operation of the PUREX Plant are given in Tables 2.27(A)-2 and 2.27(A)-3. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I. The nearby individuals receiving the highest dose equivalent are assumed to be located 16,000 m south of the source. The major pathway contributing to the individual dose equivalent rate is air immersion.

Table 2.27(A)-1. Estimated radionuclide emissions from resumed operation of the PUREX plant

Radionuclides	Emissions (Ci/y)
Carbon-14	9.0
Tritium	3.0E+3
Iodine-129	5.1E-1
Iodine-131	3.0E-1
Krypton-85	3.3E+6
Plutonium-239	5.7E-3
Strontium-90	1.2

Table 2.27(A)-2 Estimated radiation dose rates from resumed operation of the PUREX plant

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)[a]	
Red marrow	2.1	63	(59)
Endosteum	4.9	1.3E+2	(122)
Pulmonary	2.1	30	
Liver	1.0	15	(14)
Thyroid	1.5	1.4E+2	(131)

[a] The dose rates in parentheses are based on NRPB Publication R129; see Chapter 7, Volume I, of this report.

Table 2.27(A)-3. Estimated fatal cancer risks from resumed operation of the PUREX plant[a]

Source	Lifetime risk to nearby individuals		Regional population (Fatal cancers/y of operation)	
PUREX Plant	2E-5	(9E-6)	6E-3	(3E-3)

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

2.27(B) Resumption of L-Reactor Operations at Savannah River Plant

The U.S. Department of Energy has proposed resumption of operation of the L-Reactor at Savannah River Plant.

Process Description

The L-Reactor has been used to provide raw materials for nuclear weapons; it has been shut down since 1968. The plant is scheduled to be capable of operation no later than October 1983.

Radionuclide Emissions From L-Reactor Operations

Table 2.27(B)-1 gives the estimated annual emissions from resumed operations of L-Reactor. Emissions of tritium, argon-41, and xenon are the most significant radionuclides based on the quantity released.

Health Impact Assessment from Operations of the L-Reactor

The estimated dose rates from resumption of the L-Reactor are given in Table 2.27(B)-2 for the nearby individuals at the location of highest risk. This location is 9,780 meters south of the release location. Ingestion is the major pathway for dose equivalent rate. The fatal cancer risks from resumption of the L-Reactor are given in Table 2.27(B)-3. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I.

Table 2.27(B)-1 Estimated radionuclide emissions from resumption of L-Reactor operations at the Savannah River Plant

Radionuclides	Emissions (Ci/yr)
Tritium	5.5E+4
Carbon-14	1.2E+1
Argon-41	2.0E+4
Krypton-85m	6.0E+2
Krypton-87	5.4E+2
Krypton-88	8.0E+2
Xenon-133	1.7E+3
Xenon-135	1.4E+3
Iodine-129	1.0E-4
Iodine-131	4.1E-3
Plutonium-239	5.0E-7
Americium-241	5.0E-7
Strontium-90	1.0E-4

Table 2.27(B)-2. Estimated radiation dose rates from resumption of the L-Reactor, Savannah River Laboratory

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Intestine wall	4.5E-1	19.6
Red marrow	3.8E-1	15.9
Thyroid	3.7E-1	15.3

Table 2.27(B)-3. Fatal cancer risks due to radionuclide emissions from resumption of the L-Reactor, Savannah River Laboratory[a]

Source	Lifetime risk to nearby individuals		Regional population (Fatal cancers/y of operation)	
L-Reactor	7E-6	(3E-6)	4E-3	(2E-3)

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

Chapter 3: NRC LICENSED FACILITIES AND NON-DOE FEDERAL FACILITIES

3.1 Research and Test Reactors

3.1.1 General Description

This category consists of those land-based reactors licensed by the Nuclear Regulatory Commission which are operated for purposes other than commercial power production. These uses include basic and applied research and teaching. There are currently 70 such reactors licensed to operate in the United States.

3.1.2 Process Description

Research and test reactors are of a wide variety of designs, are used for different purposes, and operate over a wide range of power levels. The design types include heavy water, graphite, tank, pool, homogeneous solid, and uranium-zirconium hydride. Purposes include testing of reactor designs, reactor components, and safety features; basic and applied research in fields such as physics, biology, and chemistry; and education. Power levels range from near zero to 10 MW.

3.1.3 Control Technology

No effluent controls for argon-41 or tritium in the form of water vapor are used on research and test reactors. Some facilities use filters to remove the small quantities of fission products which may be present; others do not (Co83).

3.1.4 Radionuclide Emissions

Airborne emissions of radioactive materials from research and test reactors usually contain argon-41 and tritium as the principal radioactive constituents, and may also contain very small quantities of other noble gases and some fission products.

Some research and test reactors are not required to submit data on air emissions of radionuclides to the Nuclear Regulatory Commission (NRC). However, many reactor owners do submit these data as part of their annual operating report. A list of research and test reactors by design type, which includes their reported radionuclide emissions to air, is given in Table 3.1-1 (Co83).

3.1.5 Reference Facility

Table 3.1-2 describes the parameters of a reference reactor used to estimate the maximum impact on human health. The facility with the highest emission rates as shown in Table 3.1-1 was chosen to be the reference facility. The emission rates used in Table 3.1-2 were for a prior year, however. The actual stack height (50 m) of that facility was used. Other parameters used in the analysis were chosen to be representative of a major metropolitan area in the northeastern United States.

3.1.6 Health Impact Assessment of Reference Facility

The estimated annual radiation doses from the reference facility for nearby individuals and population groups are shown in Table 3.1-3. Fatal cancer risks to nearby individuals and to the regional population are presented in Table 3.1-4. The nearby individuals are located 1000 meters north of the stack. The risk estimates include estimates which use a dose-rate effectiveness factor of 2.5, as described in Chapter 8, Volume I.

3.1.7 Total Health Impact from Research and Test Reactors

The reference facility emits far more radioactivity than the average research or test reactor for which data are available. The total impact of research and test reactors was estimated as follows:

a. Emissions of argon-41 from reactors are roughly proportional to their power level. The reactors were grouped according to four power level ranges (0.1-0.5 MW; 0.5-1 MW; 1-5 MW; and greater than 5 MW). The average emission rate was determined for each group using the data in Table 3.1-1. Reactors having a power level of less than 0.1 MW have negligible emissions.

b. The metropolitan areas where reactors are located were classified according to the population density of the standard sites used in AIRDOS (see Appendix A). All the reactors were classified as being in standard sites A, B, and D. Only one reactor was classified as being in Site A.

c. The number of fatal cancers per year from the reference reactor was estimated for each of the three standard sites using AIRDOS.

d. The health impact may be estimated for a reactor at each site by assuming that the impact of the reactor and that of the reference reactor are in the same ratio as their emission rates. Using this relationship and the number of reactors in each power level group at the three sites, the impact from all seventy reactors may be estimated. The total estimated impact is approximately 0.06 that of the reference reactor.

3.1.8 Existing Emission Standards and Air Pollution Controls

Research and test reactors licensed by NRC are subject to the requirements of 10 CFR 20, Appendix B, Table II, which places limits on air emissions to unrestricted areas. Argon-41 is limited to an air concentration of 4×10^{-8} microcuries per milliliter above background, and tritium is limited to an air concentration of 2×10^{-7} microcuries per milliliter.

3.1.9 Supplemental Control Technology

Emissions of tritium in the form HT can be controlled by use of a catalytic recombiner.

Emissions of both argon-41 and tritium could be reduced by reducing the amount of time the reactor operates. Argon-41 emissions could also be controlled by reducing the amount of air that is irradiated by neutrons, by such techniques as filling voids with an inert gas and sealing leaks of air into the reactor compartment.

Table 3.1-1. Radionuclide emissions from research and test reactors

Design type	Power (kW)	Radionuclide	Emissions (Ci/y)
1. Heavy water	10,000	Argon-41	465.0
		Tritium	155.0
2. Tank	10,000	Argon-41	2504
		Tritium	16
3. Heavy water	5,000		N/A
4. Heavy water	5,000	Argon-41	8560
		Tritium	22
5. Pool	5,000	Argon-41	350

N/A Not available.

Table 3.1-1. Radionuclide emissions from research and test reactors (Continued)

Design type	Power (kW)	Radionuclide	Emissions (Ci/y)
6. Pool	2,000	Argon-41	247.0
7. Pool	2,000	Noble gas	47
		Radioiodine	0.021
		Particulate	0.01
8. Pool	2,000		N/A
9. Pool	2,000	Argon-41	6
10. TRIGA	1,500	Argon-41	0.09
11. TRIGA	1,500	Argon-41	2.1
12. Pool	1,000		N/A
13. TRIGA	1,000	Argon-41	9.2
14. TRIGA	1,000	Argon-41	7
15. TRIGA	1,000	Argon-41	2.9
16. Pool	1,000	Argon-41	14
17. Pool	1,000	Argon-41	10
18. TRIGA	1,000	Argon-41	41
19. TRIGA	1,000	Argon-41	2
		Particulate	0.001
20. TRIGA	1,000	Argon-41	2.6
21. TRIGA	1,000	Argon-41	1.8
22. TRIGA	1,000	Argon-41	1.2
23. TRIGA	1,000	Argon-41	1.0
24. TRIGA	250	Argon-41	0.003
25. TRIGA	250	Argon-41	0.016
26. TRIGA	250	none	0.0
27. TRIGA	250	Argon-41	0.06
28. TRIGA	250		N/A
29. TRIGA	250		N/A
30. TRIGA	250	None	0.0
31. TRIGA	250	Argon-41	0.002
32. TRIGA	250		N/A
33. TRIGA	250	Tritium	0.002
34. TRIGA	250	none	0.0
35. Pool	200	Argon-41	3.1
36. Graphite/water	100	Argon-41	33
37. Light water	100		N/A
38. TRIGA	100	Argon-41	0.001
39. TRIGA	100		N/A
40. Graphite/water	100	Argon-41	68.2

N/A Not Available.

Table 3.1-1. Radionuclide emissions from research and test reactors (Continued)

Design type	Power (kW)	Radionuclide	Emissions (Ci/y)
41. Graphite/water	100	Argon-41	113
42. Graphite/water	100	Argon-41	17
43. TRIGA	18	Argon-41	0.3
44. Special	10	none	0.0
45. TRIGA	10	none	0.0
46. Graphite/water	10		N/A
47. Pool	10		N/A
48. Pool	10		N/A
49. Pool	10		N/A
50. Homogeneous	3	none	0.0
51. Pool	1.0		N/A
52. Special	1.0		N/A
53. Special	0.1	none	0.0
54. Tank	0.1		N/A
55. Homogeneous	0.015	none	0.0
56. Homogeneous	0.01	none	0.0
57. Homogeneous	0.01	Krypton-85	3E-8
58. Homogeneous	0.006		N/A
59. Homogeneous	0.005	none	0.0
60. Homogeneous	0.005	none	0.0
61. Homogeneous	0.0001	none	0.0
62. Homogeneous	0.0001		N/A
63. Homogeneous	0.0001	none	0.0
64. Tank	0.0001		N/A
65. Homogeneous	0.0001	none	0.0
66. Homogeneous	0.0001		N/A
67. Homogeneous	0.0001		N/A
68. Pool	0.0001		N/A
69. Pulse	N/A	none	0.0
70. Pulse	N/A	Argon-41	13

N/A Not available.

Table 3.1-2. Reference facility

Parameter	Value
Type	Heavy water reflected university reactor
Power level	5,000 KW
Stack height	50 meters
Emissions	
Argon-41	9700 Ci/y
Tritium	8 Ci/y

Table 3.1-3. Radiation dose rates from radionuclide emissions from the reference facility

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Average of all organs	1.0	340

Table 3.1-4. Fatal cancer risks due to radionuclide emissions from the reference facility[a]

Source	Lifetime risk to nearby individuals	Regional population (Fatal cancers/y of operation)
Research and test reactor	2E-5 (8E-6)	0.1 (4E-2)

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

REFERENCES

Co83 Corbit C. D., Herrington W. N., Higby D. P., Stout L. A., and Corley J. P., Background Information on Sources of Low-level Radionuclide Emissions to Air, PNL-4670, Prepared for EPA under U.S. DOE Contract by Battelle Memorial Institute, September 1983.

3.2 Accelerators

3.2.1 General Description

Accelerators are devices for imparting high kinetic energies to charged particles (such as electrons, alpha particles, protons, and deuterons) by electrical or magnetic fields. In a typical operation, the accelerated particles travel in an evacuated tube or enclosure. The particles impinge on a metallic or gaseous target, producing secondary radiation.

There are three basic accelerator designs, categorized according to the means used to achieve the particle velocity: (1) constant direct current (DC) field machines, (2) incremental acceleration machines, and (3) magnetic field accelerators.

Constant DC field machines (also called "Potential-drop" machines) operate at very high voltages, establishing an electric field of constant strength through which charged particles are accelerated toward the target. These accelerators are named according to the power supply used to generate the high DC voltage. The principal design types are the Van de Graaff, Cockcroft-Walton, Dynamitron, resonant transformer, and insulating core transformer.

Incremental acceleration machines are accelerators whose electric field strength varies with time. This type of accelerator increases particle velocity in a nonlinear manner as the particle moves through the varying field. The principal design types are the linear accelerator (linac) and the cyclotron.

A magnetic field accelerator uses a time-varying magnetic field to generate an electric field which accelerates the particles. The only current example of this category is the betatron, which is used to accelerate electrons.

Accelerators have a variety of applications, including radiography, activation analysis, food sterilization and preservation, industrial processing, radiation therapy, and research. In 1977 the Bureau of Radiological Health (BRH78) estimated that there were over 1100 accelerators in use in this country, not including Federally-owned accelerators. All of the very high energy physics research accelerators are owned by the Department of Energy and are briefly discussed in Chapter 2.

Of the total number of accelerators in use, the percentage of each design type is as follows: linacs, 50 percent; neutron generators (of several different designs), 17 percent; Van de Graaff, 15 percent;

resonant and insulating core transformers, 6 percent; betatrons, 6 percent; cyclotrons, 3 percent; Cockcroft-Walton, 3 percent. Linacs are the most widely used machines, about 70 percent being used in medical applications.

3.2.2 Process Description

Radioactive emissions associated with accelerator operation are produced by two principal mechanisms: (1) the activation of air by accelerated particles or secondary radiation, resulting in radioactive carbon, nitrogen, oxygen, or argon; and (2) the loss of radioactive material (most frequently tritium) from a target into the air.

The principal air activation reactions are shown in Table 3.2-1. The formation of carbon-11, nitrogen-13, and oxygen-15 requires, at a minimum, certain threshold energies which are also listed in Table 3.2-1. These products would not be formed by accelerators which operate at low energies (typically, under 10 MeV).

Carbon-14 and argon-41 are produced by reactions involving the absorption of a neutron. The amount of radionuclides formed is in direct proportion to the neutron flux around the accelerator.

3.2.3 Control Technology

Control of air-activation products with short half-lives can be accomplished by delaying the venting of the room air. Several accelerators are capable of such holdup, but they do not use holdup as an emission control during normal operations. There are no controls in use to reduce tritium emissions. The treatment of exhaust streams prior to release is usally accomplished by high-effiency particulate air (HEPA) filters, preceded by prefilters. In some cases, adsorptive filters are necessary to remove specific types of gases. Examples include activated charcoal and molecular sieves, which are usually preceded (in line) by a particulate filter (Co83).

3.2.4 Radionuclide Emissions

Table 3.2-2 gives estimated annual radioactive emissions from three reference facilities. These values were taken from a previous EPA study of these facilities (EPA79).

3.2.5 Reference Facilities

Table 3.2-3 shows the operating parameters of the three reference accelerator facilities. The three facilities are typical of accelerators in use today. The reference facility emissions are taken from Table 3.2-2.

3.2.6 Health Impact Assessment

The health impact assessment for the reference facilities was made for a mid-western, suburban site. The nearby individuals are located 1000 meters from the stack, and there are approximately 2.5 million persons in the regional population.

The estimated annual radiation doses from the three reference particle accelerators are shown in Table 3.2-4. The individual lifetime risks and expected fatal cancers are shown in Table 3.2-5. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I.

Table 3.2-1. Nuclear reactions responsible for some airborne radioactivity

Reaction	Parent nuclide	Radionuclide produced	Threshold energy (MeV)	Half-life
(γ,n)	Nitrogen-14	Nitrogen-13	10.5	10 m
(γ,n)	Oxygen-16	Oxygen-15	15.7	2 m
(γ,n)	Carbon-12	Carbon-11	18.7	20 m
(n,2n)	Nitrogen-14	Nitrogen-13	11.3	10 m
(n,2n)	Oxygen-16	Oxygen-15	18.0	2 m
(n,2n)	Carbon-12	Carbon-11	20.0	20 m
(n,p)	Nitrogen-14	Carbon-14	NA	5730 y
(p,pn)	Oxygen-16	Oxygen-15	10.0	2 m
	Nitrogen-14	Nitrogen-13	10.0	10 m
(n,α)	Oxygen-17	Carbon-14	NA	5730 y
(n,γ)	Argon-40	Argon-41	NA	1.9 h

NA Not applicable.

m = minutes

h = hours

y = years

Table 3.2-2. Estimated annual emissions from typical particle accelerators (EPA79)

Radionuclide	100 MeV Cyclotron (Ci)	18 MeV Electron Linac (Ci)	6 MeV Van de Graaff(a) (Ci)
Carbon-11	2.0E-3		
Nitrogen-13	4.0E-2		
Oxygen-15	1.0		
Tritium			1
Carbon-14		1.0E-9	
Argon-41		1.0E-4	

(a) Tritium target used for neutron generation; release estimates include emissions from laboratory hoods due to tritium target handling operations.

Table 3.2-3. Reference accelerator facilities

Parameter	Value
Type of accelerator:	6 MeV Van de Graaff with tritium target- operating 3000 h/y 18 MeV electron linac operating 2000 h/y 100 MeV research cyclotron operating 1000 h/y
Emissions control:	None
Stack characteristics:	
Height	16.8 meters (roof type)

Table 3.2-4. Annual radiation doses due to radioactive emissions from typical accelerators (EPA80)

Type of accelerator	Nearby individuals (mrem/y)	Population (person-rem/y)
6 MeV Van de Graaff	1.1E-4	5.9E-4
18 MeV Electron linac	4.2E-8	3.1E-7
100 MeV Research cyclotron	9.6E-5	5.1E-6

Table 3.2-5. Lifetime risks to nearby individuals and number of fatal cancers due to radioactive emissions from typical accelerators (EPA80)[a]

Type of accelerator	Lifetime risk to nearby individuals		Expected fatal cancers per year of operation (Fatal cancers)	
6 MeV Van de Graaff	2E-9	(8E-10)	1E-7	(4E-8)
18 MeV Electron linac	6E-13	(2E-13)	6E-11	(2E-11)
100 MeV Research Cyclotron	1E-9	(4E-10)	1E-9	(4E-10)

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

3.2.7 Total Health Impact

The estimated total number of fatal cancers caused by all non-DOE accelerators may be calculated using the information in Table 3.2-5 and assuming that there are currently 1,500 such accelerators in operation and that 50 percent of them are linacs, 3 percent are cyclotrons, and 47 percent are constant DC field machines. The three reference facilities were assumed to be representatives of these three categories.

3.2.8 Existing Emission Standards

Accelerators are regulated by the individual States. All of the States have adopted standards equivalent to the Radiological Concentration Guides given by the Nuclear Regulatory Commission in 10 CFR 20, Appendix B, Table II. The guides for carbon-14, argon-41, and tritium are: 1E-7 microcuries/ml, 4E-8 microcuries/ml, and 2E-7 microcuries/ml, respectively. The guide for isotopes with half-lives less than two hours is 3E-6 microcuries/ml.

3.2.9 Supplemental Control Technology

Emissions of the air activation products could be reduced by the use of holdup systems. However, tritium, which dominates the total health effects, cannot be controlled by holdup due to its 12 year half-life. Experimental tritium control systems include adsorption on charcoal and cryogenic distillation, but these systems have not been commercially demonstrated.

REFERENCES

BRH78 Bureau of Radiological Health, 1978, Report of State and Local Radiological Health Programs, Fiscal Year 1977. HEW Pub. No. 78-8034, FDA, Department of Health, Education and Welfare, Rockville, Md. 20852.

Co83 Corbit C. D., Herrington W. N., Higby D. P., Stout L. A., and Corley J. P., Background Information on Sources of Low-level Radionuclide Emissions to Air, PNL-4670, Prepared for EPA under U.S. DOE Contract by Battelle Memorial Institute, September 1983.

EPA79 Environmental Protection Agency, A Study of Radioactive Airborne Effluents from Particle Accelerators, Technical Note, ORP/TAD-79-12, Washington, D.C., August 1979.

EPA80 Environmental Protection Agency, Radiological Impact Caused by Emissions of Radionuclides into Air in the United States -- Preliminary Report, EPA 520/7-79-006, Office of Radiation Programs, EPA, Washington, D.C., Reprinted 1980.

3.3 Radiopharmaceutical Industry

3.3.1 General Description

Increasing medical and research demands for radioactive chemicals have resulted in the evolution of a large radiopharmaceutical industry. This industry comprises the suppliers that produce or package radiopharmaceuticals, the users of radiopharmaceuticals, and waste-receiving facilities. Suppliers include manufacturers and nuclear pharmacies. Manufacturers include companies that manufacture radionuclides for use as raw materials by other radiopharmaceutical companies, and companies that process radionuclides into radiopharmaceuticals and radioimmunoassay (RIA) kits (TI79). Nuclear pharmacies obtain bulk amounts of radiopharmaceuticals and repackage them for distribution.

Users include hospitals and private physicians that dispense pharmaceuticals and medical and research laboratories that utilize RIA materials. Of all users, hospitals contribute the most airborne radioactivity because most nuclear medicine procedures are performed at hospitals.

Waste-receiving facilities that receive wastes from suppliers and users of radiopharmaceuticals have the potential to produce airborne emissions of radionuclides. These facilities include incinerators and sewage treatment plants. It is estimated that more than 90 percent of the airborne radioactive emissions from waste-receiving facilities are from sewage treatment plants (TI79).

Suppliers

Industrial suppliers produce 65 different, generally-used radionuclides (EPA80). Major suppliers of radiopharmaceuticals and medical isotopes are listed in Table 3.3-1 (TI79). This list does not include nuclear pharmacies.

Iodine-131, iodine-125, xenon-133, and technetium-99m have been identified as the radionuclides having the greatest potential for release as airborne effluents from radiopharmaceutical suppliers (Le79).

Users

Radionuclides are extensively used for medical diagnosis, therapy, and research. The number of medical facilities using radioactive materials has grown from 38 in 1946 to over 10,000 NRC and Agreement State licensees in 1977. In 1977 alone, it is estimated that there were 15 million in-vivo and 20 million in-vitro therapeutic and diagnostic procedures performed using radiopharmaceuticals (TI79). Radionuclides used in diagnostic and therapeutic procedures are listed in Table 3.3-2 (FDA76, NRC79).

Table 3.3-1. Major suppliers of radiopharmaceuticals and medical isotopes, excluding nuclear pharmacies (TI79)

Location	Supplier	Product
California		
Emeryville	Medi-Physics, Inc. (home office)	Indium-111, Iodine-123, Gallium-67, Rubidium-81/ Krypton-81m generators, Xenon-133, Technetium-99m.
Glendale	Medi-Physics, Inc.	Technetium-99m-labeled compounds.
Vallecitos	General Electric Company	Xenon-133.
Van Nuys	Nuclear Med. Svcs.,Inc.	Groups I, II, & IV(a).
San Ramon	Gammaceutics	Iodine-123.
Davis	University of California	Iodine-123.
Irvine	ICN Pharmaceuticals	RIA kits(b).
Richmond	Bio-Rad Laboratories	Iodine-125, Cobalt-57, RIA kits.
Florida		
Miami Lakes	Medi-Physics, Inc.	Technetium-99m-labeled compounds.
Georgia		
East Point	Medical Research Foundation, Inc.	Yttrium-90 microspheres.
Illinois		
Arlington Heights	Amersham Corporation	Cobalt-58 as cyanocobalamin, Selenium-75 as selenomethionine, Iodine-125 as fibrinogen.
Rosemont	Medi-Physics, Inc.	Technetium-99m as pertechnetate. Kits for preparation of Tc-99m labeled material.

See footnotes at end of table.

Table 3.3-1. Major suppliers of radiopharmaceuticals and medical isotopes, excluding nuclear pharmacies (TI79) (continued)

Location	Supplier	Product
Indiana		
Indianapolis	Bio-Dynamics	Kits for preparation of Tc-99m-labeled DTPA(c), and pyrophosphate.
Elkhart	Miles Laboratories Ames Company	Iodine-125 RIA kits.
Massachusetts		
Billerica	Cambridge Nuclear Radiopharmaceutical Corp.	Kits for preparation of Tc-99m-labeled pyrophosphate, DTPA.
	New England Nuclear Corp.	Thallium-201, Gallium-67, Iodine-131, Iodine-125 Selenium-75, Phosphorus-32, Mo-99/Tc-99m generators.
Attleboro Falls	Gamma Diagnostics Lab.	Tc-99m as pertechnetate, sulfur colloid, aggregated albumin.
Boston	New England Nuclear Corp. Radiopharmaceutical Div.	Organic compounds labeled with Tritium, Carbon-14, Phosphorus-32, and Sulfur-35.
Bedford	CIS Radiopharmaceuticals, Inc.	Kits for preparation of Tc-99m-labeled DTPA, albumin, pyrophosphate, sulfur colloid, and aggregated albumin.
Minnesota		
St. Paul	Minnesota Mining & Manufacturing Co.	Kits for preparation of Tc-99m-labeled materials. Ytterbium-169 as DTPA.
Missouri		
St. Louis	Mallinckrodt, Inc. Diagnostic Products Div.	Kits for preparation of Tc-99m-labeled materials; Chromium-51, Iron-59, Mercury-197, Iodine-125, Phosphorus-32, Selenium-75, Mo-99/Tc-99m generators.
Columbia	University of Missouri	Molybdenum-99 (as raw material).

See footnotes at end of table.

Table 3.3-1. Major suppliers of radiopharmaceuticals and medical isotopes, excluding nuclear pharmacies (TI79) (continued)

Location	Supplier	Product
New Jersey		
Princeton	E.R. Squibb & Sons, Inc.	Kits for preparation of Tc-99m-labeled materials, Gold-198, Chromium-51, Mercury-197, Iodine-131, Iodine-125, Phosphorus-32, Selenium-75, Strontium-85, Cobalt-60, Mo-99/Tc-99m generators.
S. Plainfield	Medi-Physics, Inc.	Iodine-123, Gallium-67, Tc-99m, Indium-111, Rb-81/Kr-81m generators.
Ohio		
Cincinnati	Procter and Gamble Co.	Kits for preparation of Technetium-99m, disodium etidronate.
New York		
Tuxedo	Union Carbide Corp.	Tc-99m, Xenon-133, Iodine-131, Iodine-125, Mo-99/Tc-99m generators.
Virginia		
Richmond	Va. Commonwealth Univ.	Kits for preparation of Tc-99m-labeled materials, sulfur colloid, aggregated albumin.

[a] See 10 CFR 35.100, Schedule A.
[b] RIA Radioimmunoassay.
[c] DTPA Diethylenetriamine pentaacetic acid.

Table 3.3-2. Major radiopharmaceuticals and their uses (FDA76, NRC79)

Radionuclide	Use
Phosphorus-32	Bone marrow therapy
Gallium-67	Tumor localization
Rubidium-81	Myocardial imaging
Technetium-99m	Bone imaging, brain imaging, liver imaging, lung perfusion, myocardial imaging, blood pool, renograms, thyroid imaging, thyroid uptake, renal imaging
Iodine-123	Thyroid imaging Thyroid uptake
Iodine-125	Renograms
Iodine-131	Renal imaging, renograms, thyroid imaging, thyroid uptake, tumor localization and therapy
Xenon-133	Lung ventilation
Mercury-203	Renograms
Thallium-201	Myocardial imaging

Iodine-131, iodine-125, xenon-133, and technetium-99m have been identified as having the greatest potential for release as airborne effluents from medical facilities. Although releases are much more likely if the nuclide is easily volatilized, technetium-99m is included because of the large quantities used in hospitals. Xenon is used primarily in diagnostic procedures with approximately 62 percent used in large hospitals (over 500 beds).

Iodine is used for diagnostic and therapeutic procedures with approximately 60 percent used in large hospitals. Estimated quantities of radionuclides received and used by hospitals in 1977 are listed in Table 3.3-3.

Table 3.3-3. Estimated quantities of radionuclides received and used by hospitals, 1977 (TI79)

Radionuclide	Quantity (Ci)	
	Received	Used
Iodine-131	900-1500	300-1350
Xenon-133	2,700-3,300	1,600-2,000
Technetium-99m	26,000-34,000	15,000-30,000

Waste-Receiving Facilities

Most of the radionuclides used at medical facilities are released via the liquid pathway to the sanitary sewer system. When sewage and sludge containing this material are treated in a sewage treatment plant, radionuclides may be emitted into the air.

Iodine-131, iodine-125, and technetium-99m have the greatest potential for release as airborne effluents from sewage treatment plants (TI79).

3.3.2 Process Description

Radionuclides used in the radiopharmaceutical industry are produced by irradiation of target materials (or fuel) in a reactor or accelerator, and by radioisotope generators.

Suppliers

Radionuclide manufacturing involves complex chemical processes that have the potential for releasing radioactive materials to the environment. Most radionuclides produced for use in the industry are made in nuclear reactors by one of the reactions shown in Table 3.3-4. The most common of these is the neutron-gamma reaction because many elements capture neutrons easily. It is estimated that reactor-produced isotopes account for 60 to 80 percent of the market (TI79).

Table 3.3-4. Nuclear reactions used in radioisotope production

Reaction	Examples
(1) Neutron-gamma (n,γ)	$^{59}Co + n \rightarrow {}^{60}Co + \gamma$
(2) Neutron-proton (n,p)	$^{32}S + n \rightarrow {}^{32}P + p$
(3) Neutron-alpha (n,α)	$^{35}Cl + n \rightarrow {}^{32}P + \alpha$

In a reactor, the main steps in radionuclide production are as follows (Ba66):

1. A suitable target is prepared and irradiated with neutrons.

2. The irradiated target is processed by dissolution or by more complicated separations (including ion exchange, precipitation, and distillation) to remove undesirable impurities, or to concentrate the product nuclide.

3. Radionuclides are placed in inventory, dispensed, and packaged for shipment.

Many radionuclides are produced in particle accelerators, such as the cyclotron. Amounts of radioactive materials produced in accelerators are smaller than amounts produced in reactors.

The cyclotron can be used to produce nuclides having decay characteristics that are preferable to other isotopes of the same element that are produced in reactors and isotopes of elements for which no reactor-produced nuclides exist. Examples of accelerator-produced radionuclides are iodine-123, iron-52, mercury-199m, carbon-11, nitrogen-13, and oxygen-15.

Typical nuclear pharmacy production activities include processing, mixing or compounding, and distribution of prepared radiopharmaceuticals.

There is a growing trend for nuclear pharmacies to operate radioisotope generators for the production of certain radionuclides having short half-lives; for example, technetium-99m. Radioisotope generators make nuclides with short half-lives available at long distances from the source of production. These generators consist of a longer-lived parent nuclide that produces the short-lived daughter as it decays. In the generator, the daughter nuclide is chemically separated at intervals, leaving the parent nuclide to generate more of the daughter.

Users

In hospitals, radionuclides are generally handled in solid or liquid form, except for some radioactive gases, notably xenon. This tends to decrease the likelihood of release of airborne effluents.

Therapeutic iodine-131, generally in the form of sodium iodide, is readily volatilized, and can become an airborne contaminant when used in some therapeutic procedures.

Xenon-133 can also be released as an airborne effluent. Because of a low biological half-life, relatively large amounts are administered for lung-imaging procedures. Following administration, patients exhale xenon-133 gas into a spirometer. The exhaust from this instrument exits the hospital through a roof vent, with or without treatment.

Technetium-99m is used in large quantities in hospitals, and is obtained directly from the manufacturer or from the nuclear pharmacy where it is produced in a radioisotope generator from molybdenum-99. Although not a gaseous or volatile isotope, technetium-99m is a potential airborne effluent because of the quantities used in nuclear medicine procedures.

Waste-Receiving Facilities

Radionuclide releases at sewage treatment plants depend upon several factors. The chemical and physical properties of wastewater and sludge influence the potential amount of radioactivity released; e.g., the potential for release is greater at points in the treatment process where wastewater pH is acidic. Other factors that affect radionuclide releases include decay losses, evaporative losses, solids removal, degree of system retention, and dilution.

Sludge treatment processes (drying and incineration) are the greatest sources of radionuclide emissions from sewage treatment plants because the high temperatures employed in these processes (typically 725°C) volatilize iodine and technetium. In addition, sludge incineration has the smallest time delay compared with other sludge treatment processes, and the greatest potential for release of particulates caused by mechanical agitation of ash and combustion gases in the incinerator (TI79).

It is estimated that approximately 21 percent of the sewage treatment facilities in the U.S. employ incineration or pyrolysis for sludge treatment (TI79). In a treatment facility, sludge is typically concentrated in settling tanks before it is concentrated further in another sludge treatment process (e.g., centrifugation). Following this process, the sludge is conveyed to an incinerator and burned at temperatures up to 815°C.

3.3.3 Control Technology

Types of effluent controls employed by producers of radiopharmaceuticals depend on the type and amount of each nuclide handled in the facility (Le80). All suppliers handling large amounts of iodine, and some dealing in smaller quantities, handle this material in hot cells or fume hoods that exhaust through HEPA and/or activated carbon filters before release through a roof-mounted vent stack. Some suppliers that handle small amounts of radioiodine, or only nonvolatile nuclides such as molybdenum and technetium, use no filters, or only HEPA filters on fume hoods and building ventilation exhausts. This exhaust is usually released from a short vent stack (2 to 3 m high) on top of the building (TI79). Xenon manufacturers generally use ventilation controls only. One large producer controls radioactive xenon emissions by cryogenically liquefying hot cell off-gas, and holding it for decay.

Small hospitals (less than 300 beds) generally operate with no effluent controls because the total activity of the principal isotope used (technetium-99m) is low, and because it is handled in solution. Hospitals in the medium-size range (300 to 500 beds) generally use xenon traps and unfiltered fume hoods, but may use controls similar to those of the larger hospitals if large amounts of activity are handled daily. Some hospitals capture patient xenon exhalations for holdup in retention bags before release. Other medium-size hospitals may have no controls if radiopharmaceuticals are administered infrequently, or if their emissions meet NRC MPC requirements without controls. Larger hospitals (over 500 beds) generally use controls similar to those used by suppliers because of the large amounts of activity handled, and because of the variety of radioisotopes used. Controls at large hospitals range from fume hoods with HEPA and activated carbon filters and xenon traps or retention bags to unfiltered fume hoods and no xenon controls (TI79).

3.3.4 Radionuclide Emission Measurements

Suppliers

Data presented in this section are drawn from emissions data submitted to EPA by medical isotope producers and from reports of surveys conducted at several radiopharmaceutical manufacturing firms. The emissions data represent airborne releases from normal operations as measured by company-owned or contractor monitoring systems. Average annual emissions of six radiopharmaceutical suppliers are listed in Table 3.3-5.

The NRC conducted a survey of over 3000 by-product material licensees in late 1980 to collect annual radioactive effluent emissions data (NRC81). Three hundred and eight-five industrial licensees responded to the survey. Table 3.3-6 summarizes emissions data for the facilities manufacturing radionuclides.

A report prepared for EPA includes average release rates for radiopharmaceutical manufacturers and radiopharmacies (Cob83). Because large releases from a single manufacturing facility are included, releases should not be considered typical. For this reason, emissions from this facility are listed separately in Table 3.3-7.

Table 3.3-5. Radionuclide emissions from six major radiopharmaceutical producers (Coa82, EPA80, Fr82a, Fr82b, Ro82a, Ro82b)

Producing Plant	Emissions (Ci/y)		
	Iodine-125	Iodine-131	Technetium-99m
A	1.8E-2	3.9E-4	-
B	2.2E-6	-	-
C	-	-	4.14E-3
D	-	-	4.5E-3
E	1.0E-2	7.6E-2	-
F	2.6E-3	3.1E-2	-

Table 3.3-6. Summary of reported atmospheric emissions of radionuclides from 385 industrial facilities (NRC81)

Source	Number of facilities using nuclide	Number of facilities reporting releases	Emissions (Ci/y)		
			Mean	Maximum	Minimum
Iodine-131	11	4	1.8E-4	4.6E-4	3.0E-5
Iodine-125	55	25	1.7E-3	2.0E-2	3.0E-8
Xenon-133	6	4	7.0	2.3E+1	2.0E-2
Molybdenum-99	4	4	8.3E-6	3.0E-5	1.5E-7
Technetium-99m	2	1	3.2E-6	3.2E-6	3.2E-6
Tritium	66	21	5.1E+1	7.4E+2	1.0E-4

Users

The survey conducted by the NRC (NRC81) also included radioactive emissions data for 860 government and public medical facilities. These data are summarized in Table 3.3-8. A survey conducted by Battelle Memorial Institute to update the emissions was generally in agreement with the values listed in the table (Cob83).

Table 3.3-7. Radionuclide emissions from a large radiopharmaceutical producer (Cob83)

Radionuclide	Emissions (Ci/y)
Krypton-83m	6.1E+2
Krypton-85	2.3
Krypton-85m	1.7E+3
Krypton-87	1.6E+2
Iodine-125	2.3
Iodine-131	3.4
Xenon-133	1.9E+4
Xenon-133m	2.2E+3
Xenon-135	1.1E+4
Argon-41	1.2E+3

Table 3.3-8. Summary of reported atmospheric emissions of radionuclides from 860 government and public medical facilities (NRC81)

Source	Number of facilities using nuclide	Number of facilities reporting releases	Emissions (Ci/y		
			Mean	Maximum	Minimum
Iodine-131	346	25	2.9E-3	5.0E-2	2.0E-8
Iodine-125	270	19	1.7E-3	9.5E-3	1.0E-8
Xenon-133	229	142	4.6E-1	6.4	2.0E-5
Molybdenum-99	268	3	1.0	3.0	1.0E-8
Technetium-99m	73	2	2.8E-1	5.0E-1	5.2E-2
Cobalt-60	112	6	1.3E-2	7.2E-2	1.0E-7

Sewage Treatment Plants

Radioactive airborne emissions resulting from sludge drying and incineration at a sewage treatment plant were studied (TI79) and estimated to be 5.0E-4 Ci/y for iodine-131 and 8.0E-4 Ci/y for technetium-99m. This report also estimated that about 4000 sewage treatment plants in the United States employ these sludge treatment processes.

3.3.5 Reference Facilities

Radiopharmaceutical Supplier Facility

The radiopharmaceutical supply industry can be characterized as generally urban, with suppliers located near their major users, hospitals (TI79). Table 3.3-9 describes the parameters of a typical radiopharmaceutical production plant. These parameters were used to estimate health impacts resulting from emissions from the reference facility.

The typical facility produces technetium-99m, xenon-133, iodine-131, iodine-125, and molybdenum-99/technetium-99m generators (EPA80). Airborne releases are discharged from a single stack. Atmospheric emissions from the reference facility are listed in Table 3.3-10. Emissions from the reference facility were chosen as equal to emissions from facilities having the highest values listed in Tables 3.3-5 and 3.3-6.

Emissions from the reference facility are controlled by charcoal beds and HEPA filters.

User Facility

Parameters that describe the reference medical facility are listed in Table 3.3-9. These parameters represent a typical large hospital. It is assumed that the hospital has nuclear medicine capabilities, and administers an average of 0.5 curies per year of iodine-131, 0.05 curies per year of iodine-125, and 25.0 curies per year of xenon-133.

Estimated annual atmospheric emissions from the reference medical facility are listed in Table 3.3-10. These emission estimates represent maximum emission levels for I-131, I-125, and Xe-133 from sources described in Table 3.3-8. Although molybdenum-99 and technetium-99m are used at the reference facility, releases are assumed to be zero because, as indicated in Table 3.3-8, airborne releases are rarely observed for these nuclides.

Sewage Treatment Facility

The reference sewage treatment plant dries and incinerates sludge. Atmospheric emissions from a typical sewage treatment plant

Table 3.3-9. Reference facilities of typical suppliers and users of radiopharmaceuticals

Parameter	Value
Supply Facility	
Product line:	Iodine-131, iodine-125, xenon-133, technetium-99m, molybdenum-99/technetium-99m generators
Emission controls:	Activated carbon/HEPA filters with release through a single elevated stack
Stack parameters:	Height: 15 meters
User Facility	
Size:	500+ beds
Volume of administrations:	Iodine-131, 0.5 Ci/y Iodine-125, 0.05 Ci/y Xenon-133, 25.0 Ci/y
Emission controls:	Exhaust hoods with carbon and HEPA filters. Release through building ventilation roof vents. Vent height: 10 m
Sewage Treatment Plant	
Process:	Sludge drying and incineration

that employs these processes are listed in Table 3.3-10. These emission estimates are based on a study of airborne emissions from a sewage treatment plant (TI79).

3.3.6. Health Impact Assessment of Reference Radiopharmaceutical Industry Facilities

The estimated annual radiation doses from radionuclide emissions from the reference radiopharmaceutical supply facility, medical facility, and sewage treatment plant are listed in Table 3.3-11. These estimates are for the near suburbs of a large midwest city with a regional population of 2.5 million (Reference Site B). Nearby

Table 3.3-10. Radionuclide emissions from reference radiopharmaceutical industry facilities

Source/Radionuclide	Emissions (Ci/y)
Supply Facility	
Iodine-125	2.0E-2
Iodine-131	7.6E-2
Xenon-133	2.3E+1
Technetium-99m	4.5E-3
User Facility	
Iodine-125	9.5E-3
Iodine-131	5.0E-2
Xenon-133	6.4
Sewage Treatment Plant	
Iodine-131	5.0E-4
Technetium-99m	8.0E-4

Table 3.3-11. Radiation dose rates from radionuclide emissions from the reference radiopharmaceutical industry facilities

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Radiopharmaceutical supplier		
Thyroid	3.2E-1	2.5
Medical facility		
Thyroid	3.7E-2	1.9E-1
Sewage treatment plant		
Thyroid	8.0E-4	7.4E-3

individuals are located 500 meters from the supply facility, 500 meters from the medical facility, and 500 meters from the sewage treatment plant.

Table 3.3-12 presents estimates of the lifetime risk to nearby individuals and the number of fatal cancers to the regional populations from these doses. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I.

3.3.7 Health Impact Assessment of Specific Radiopharmaceutical Facilities

In a recent survey of radiopharmaceutical users, EPA identified those facilities which have the largest radionuclide emission rates and estimated the resulting dose to nearby persons (JFA84). Most of the 32 facilities contacted in the survey were large medical centers. Twenty-three facilities cooperated with the survey and gave useful information. Iodine-125 is the radionuclide of concern at most facilities. At some facilities, however, xenon-133 or iodine-131 is the radionuclide of concern. All of the facilities, with the possible exception of one, have emissions that result in doses of less than 10 mrem/y to any organ. A more accurate calculational technique than that used in this survey may produce dose estimates of less than 10 mrem/y for this facility, however.

Table 3.3-13 lists the estimated doses from radionuclide emissions from the radiopharmaceutical production facility. The emissions from this facility are listed in Table 3.3-7. The nearby individuals are located 1500 meters from the facility.

The estimates of the lifetime risk to nearby individuals and the number of fatal cancers for the regional population resulting from these doses are listed in Table 3.3-14. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I.

3.3.8 Total Health Impact of the Radiopharmaceutical Industry

For all segments of the radiopharmaceutical industry, the estimated total health impact may be obtained as follows.

Suppliers

The estimated total health impact caused by all radiopharmaceutical suppliers is based on the assumptions that (1) emissions of I-125, I-131, Xe-133, and Tc-99m reported for industrial facilities in a survey by NRC (NRC81) are from radiopharmaceutical suppliers; and (2) the number of industrial licensees in non-Agreement States, for which data were not available, is approximately equal to the number of licensees in Agreement States.

Table 3.3-12. Fatal cancer risks due to radionuclide emissions from the reference radiopharmaceutical industry facilities[a]

Source	Lifetime risk to nearby individuals		Regional population (Fatal cancers/y of operation)	
Radiopharmaceutical supplier				
	2E-7	(1E-7)	2E-5	(9E-6)
Medical facility				
	2E-8	(1E-8)	8E-7	(4E-7)
Sewage treatment plant				
	2E-10	(2E-10)	3E-8	(3E-8)

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

Table 3.3-13. Radiation dose rates from radionuclide emissions from a large radiopharmaceutical producer

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Thyroid	3.3	4.1E+1

Data presented in the NRC survey (NRC81) showed that approximately 15 percent of industrial licensees in the survey handled I-125, 3 percent handled I-131, and less than 2 percent handled Xe-133 and Tc-99m. Based on these figures and the above assumptions, the total numbers of suppliers in the United States handling I-125 and I-131 are 328 and 66, respectively. Although the number of suppliers handling Xe-133 and Tc-99m would be less than 44, this figure will be used for estimation purposes.

Table 3.3-14. Fatal cancer risks due to radionuclide emissions from from a large radiopharmaceutical producer[a]

Source	Lifetime risk to nearby individuals		Regional population (Fatal cancers/y of operation)	
Radiopharmaceutical producer	6E-6	(3E-6)	7E-3	(3E-3)

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

Assuming that available average emissions data (Tables 3.3-5 and 3.3-6) are typical of the entire industry, total annual emissions from all radiopharmaceutical suppliers are as follows: I-125, 0.82 Ci/y; I-131, 0.99 Ci/y; Xe-133, 310 Ci/y; and Tc-99m, 0.13 Ci/y.

Based on these emissions, releases from the reference facility (Table 3.3-10) are 2.4 percent of the national total for I-125, 7.7 percent for I-131, 7.4 percent for Xe-133, and 3.5 percent for Tc-99m. Assuming that the reference facility also causes equal percentages of total health impact, the impact from all radiopharmaceutical suppliers may then be calculated.

Users

Assuming that the number of medical facility licensees in non-Agreement and Agreement States is approximately equal, data in the NRC survey (NRC81) indicate that approximately 1,100 facilities in the U.S. use I-125, 1,200 facilities use I-131, and 800 use Xe-133.

If the average emissions listed in Table 3.3-8 are assumed to be typical of all medical facilities, total annual emissions from all medical facilities are as follows: I-125, 1.9 Ci/y; I-131, 3.5 Ci/y; and Xe-133, 370 Ci/y.

Emissions from the reference facility contribute 0.5 percent of the total I-125 emission, 1.4 percent of the total I-131 emission, and 1.7 percent of the Xe-133 emission. Assuming that the reference facility contributes equal percentages to the total health impact, the impact from all medical facilities may be estimated.

Sewage Treatment Plants

It has been estimated that approximately 4000 sewage treatment plants in the U.S. employ sludge incineration or pyrolysis (TI79).

Assuming that emissions from the reference facility are typical of emissions from all sewage treatment plants that incinerate sludge, the total annual emissions of I-131 and Tc-99m are 2.0 Ci/y and 3.2 Ci/y, respectively. The total health impact from all sewage treatment plants may then be calculated.

3.3.9 Existing Emission Standards and Air Pollution Controls

Suppliers and users of radiopharmaceuticals are either NRC or Agreement State licensees and are therefore required to limit effluent releases to unrestricted areas to the maximum permissible concentrations of 10 CFR 20, Appendix B, Table II. There are no radionuclide emission standards for sewage treatment plants.

3.3.10 Supplemental Control Technology

Suppliers

Existing emission controls typically employed at supplier facilities (HEPA and carbon beds/filters) effectively remove particulates and radioiodines, but not radioactive noble gases.

Supplemental methods for controlling noble gas releases include cryogenic systems and hold-up tanks. The performance of cryogenic systems in large commercial facilities has not yet been demonstrated, nor is there an approved disposal method for the concentrated, potentially long-lived, high-activity wastes that these systems produce (TI79). Hold-up tanks are best suited to effluents with low release rates which contain short-lived noble gases.

Because the entire volume of effluent must be retained to allow for decay, hold-up is feasible only at very low release rates. Since exhaust rates at supplier facilities typically are in the range of 10^5 to 10^6 liters per minute, the tanks required for hold-up would be too large and too costly to be practical. Implementation of supplemental controls for noble gas control at supply facilities is, therefore, not currently practicable.

Users

Xenon retention bags, which are now in use at some medical facilities, are a feasible means of reducing radioactive emissions because of low release rates of xenon-133. The costs and risk reductions achieved by adding supplementary controls to capture patient xenon exhalations at the reference medical facility are shown in Table 3.3-15.

Airborne radioactive iodine emissions may be controlled by using an activated charcoal filter in an iodination box in conjunction with a fume hood (DM80). An iodination box is used at some facilities for all procedures involving the use of 1 mCi or more of radioiodine. Basically, it is a box with two 5-inch-diameter portholes and a front opening door for access during experimental work. With the filter filled with activated charcoal, initial collection efficiencies between 90 and 100 percent have been measured.

The cost of an iodination box is $700-$2,000. The cost to adapt a fume hood for charcoal filter use is $1000-$2,000. The annual costs to replace the filter are approximately $70 for an iodination box and approximately $5000 for a fume hood.

Sewage Treatment Plants

Sewage treatment plants employing sludge incineration typically use dry cyclones and wet scrubbers to control gaseous and particulate emissions. Supplementary controls consist of charcoal filters to reduce iodine emissions and HEPA filters to reduce particulate emissions of technetium. HEPA filters are required upstream of the charcoal filters to prevent plugging.

Costs and risk reductions achieved by adding these supplementary controls to the incinerator stacks of the reference sewage treatment plant to reduce iodine-131 and technetium-99m emissions are shown in Table 3.3-15.

Table 3.3-15. Costs and risk reductions of adding supplemental controls to reference radiopharmaceutical industry facilities

Type of control	Level of control	Annual[a] cost ($1000)	Fatal cancer risk reduction factor
Medical facility			
No xenon controls[b]	0	---	1
Add retention bags or xenon traps	99.9	25.0	1E-3
Sewage treatment plant			
Dry cyclone and scrubber[b]	90[c]	---	1
Add HEPA filter with preheater and charcoal filter	99[c] 90[d]	50.0	0.1

[a] Does not include capital costs.
[b] Typical existing controls.
[c] Particulates.
[d] Iodines.

REFERENCES

Ba66	Baker P. J., Reactor Produced Radionuclides, in AEC Symposium Series No. 6, Radioactive Pharmaceuticals, Conf 651111, April 1966.
Coa82	Cole L. W., Environmental Survey of the Manufacturing Facility, Medi-Physics, Inc., Arlington Heights, Illinois, Oak Ridge Associated Universities, Oak Ridge, Tennessee, January 1982.
Cob83	Corbit C. D., Herrington W. N., Higby D. P., Stout L. A., and Corley J. P., Background Information on Sources of Low-level Radionuclide Emissions to Air, PNL-4670, Prepared for EPA under U.S. DOE Contract by Battelle Memorial Institute, September 1983.
DM80	Dames and Moore, Airborne Radioactive Emission Control Technology. Prepared for EPA under Contract No. 68-01-4992, 1980.
EPA80	Environmental Protection Agency, Radiological Impact Caused by Emissions of Radionuclides into Air in the United States--Preliminary Report, EPA 520/7-79-006, Office of Radiation Programs, EPA, Washington, D.C., Reprinted 1980.
FDA76	Food and Drug Administration, A Pilot Study of Nuclear Medicine Reporting Through the Medically Oriented Data System, HEW (FDA) 76-8045, June 1976.
Fr82a	Frame P. W., Environmental Survey of the New England Nuclear Corporation, Boston, Massachusetts, Oak Ridge Associated Universities, Oak Ridge, Tennessee, April 1982.
Fr82b	Frame P. W., Environmental Survey of the New England Nuclear Corporation, Billerica, Massachusetts, Oak Ridge Associated Universities, Oak Ridge, Tennessee, April 1982.
JFA84	Jack Faucett Associates, Impact of Proposed Clean Air Act Standards for Radionuclides on Users of Radiopharmaceuticals. Prepared for EPA under contract, October 1984.
Le79	Leventhal L., et al., Radioactive Airborne Effluents from the Radiopharmaceutical Industry, in Proceedings of the Health Physics Society, 24th Annual Meeting, Philadelphia, Pa., 1979.
Le80	Leventhal L., et al., A Study of Effluent Control Technologies Employed by Radiopharmaceutical Users and Suppliers, in: Book of Papers, International Radiation Protection Association, 5th International Congress, Volume II, Jerusalem, Israel, 1980.

REFERENCES
(Continued)

NRC79 Nuclear Regulatory Commission, Private Communication from G. Wayne Kerr, NRC, Washington, D.C., 1979.

NRC81 Nuclear Regulatory Commission, A Survey of Radioactive Effluent Releases from Byproduct Material Facilities, NUREG-0819, Office of Nuclear Material Safety and Safeguards, NRC, Washington, D.C., 1981.

Ro82a Rocco B. P., Environmental Survey of the Medi-Physics Facility, South Plainfield, New Jersey, Oak Ridge Associated Universities, Oak Ridge, Tennessee, January 1982.

Ro82b Rocco B. P., Environmental Survey of the E. R. Squibb and Sons Facility, New Brunswick, New Jersey, Oak Ridge Associated Universities, Oak Ridge, Tennessee, March 1982.

TI79 Teknekron, Inc., Draft Final Report, A Study of Airborne Radioactive Effluents from the Radiopharmaceutical Industry, EPA Contract No. 68-01-5049, March 1979.

3.4 Radiation Source Manufacturers

3.4.1 General Description

The term "radiation source" refers to radioactive material which is enclosed in a sealed container or other nondispersible matrix. Radiation sources are used in a wide variety of industrial and consumer products including: (1) radioisotope gauges, which measure the thickness of industrial products, (2) static eliminators, which are used to reduce static electricity in industrial machines, (3) nondestructive testing equipment, (4) self-illuminating signs and watch dials, and (5) smoke detectors (EPA79).

3.4.2 Process Description

Radiation source manufacturers process bulk quantities of radioactive materials received from radionuclide production facilities such as accelerators or reactors. During the manufacturing process, the radioactive materials are handled with remote manipulators and custom-made enclosures, such as glove boxes.

The manufacturers are licensed by NRC to have inventories of radioactive materials in quantities ranging from ten Ci to as high as 100,000 Ci.

3.4.3 Emission Control Systems

Radiation source manufacturers use many different radionuclides in their operations. In addition to conventional filtration systems for removal of particulate matter, manufacturers may use other kinds of treatment systems which are applicable to their particular emissions. For example, tritium emissions can be reduced by use of desiccant type scrubber columns which remove tritiated water; radioiodine releases can be controlled with charcoal filters; facilities with emissions of krypton or xenon can use chilled charcoal traps to delay the release of these gases until radioactive decay has reduced their activity.

3.4.4 Radionuclide Emissions

Each radiation source manufacturer handles a unique combination of radionuclides; therefore, each site has unique emission characteristics. Table 3.4-1 shows radionuclide emission data on eighteen manufacturing sites; these data were taken from reports submitted to NRC.

3.4.5 Reference Facility

For this analysis, a reference facility was created by summing all of the radionuclides emitted by the eighteen sites listed in Table 3.4-1. Other parameters used in the analysis were assumed to be those of an industrial zone in a suburban area adjacent to a major city in the midwestern United States. Table 3.4-2 describes the parameters of the reference facility.

3.4.6 Health Impact Assessment of Reference Facility

The estimated annual radiation doses from the reference facility for individuals and population groups are shown in Table 3.4-3. Cancer risks to nearby individuals and committed population fatal cancers are presented in Table 3.4-4. Nearby individuals are located 500 meters north of the source. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I.

Because of the way in which the reference facility was artificially created, the risk to nearby individuals estimated for the reference facility is much higher than the actual risk associated with any individual site. The population risk estimated for the reference facility is equal to the total population risk for the eighteen sites listed in Table 3.4-1.

3.4.7 Total Health Impact

The estimated number of fatal cancers caused by all radiation source manufacturers is the same as the reference facility, because of the way in which the reference facility was created.

3.4.8 Existing Emission Standards and Air Pollution Controls

Radiation source manufacturers licensed by NRC are subject to the requirements of 10 CFR 20.106, which places limits on air emissions to unrestricted areas. The particular controls used by a licensee to meet these requirements will depend on the particular radionuclide(s) involved and other factors unique to that licensee.

Table 3.4-1. Radionuclide emissions from radiation source manufacturers (Co83)

Site	Radionuclide	Emissions (Ci/y)
A	none	0.0
B	Kr-85	1.3
C	H-3	3E-1
D	Kr-85	5E-1
E	Th-232	1.4E-1
F	Kr-85	1E-3
G	H-3	5.4E+1
	Kr-85	5E+1
H	H-3	5E+1
I	none	0.0
J	I-125	2E-2
	Kr-85	2.5
	Cs-137	2E-3
K	H-3	2.14E+2
	C-14	4.3
	S-35	1.2E-1
L	H-3	2.5E-1
M	H-3	7.4E+2
N	H-3	3E-1
O	H-3	3E-2
P	Kr-85	2E-1
Q	Kr-85	2E-3
	Xe-133	2E-2
R	Kr-85	7.3

Table 3.4-2. Reference radiation source manufacturer

Parameter	Value
Fraction of radionuclides released:	
Tritium	1060
Krypton-85	61.8
Carbon-14	4.3
Stack height	10 meters

Table 3.4-3. Radiation dose rates from radionuclide emissions from the reference radiation source manufacturer

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Average of all organs	0.22	8.4

Table 3.4-4. Fatal cancer risks due to radionuclide emissions from the reference radiation source manufacturer(a)

Source	Lifetime risk to nearby individuals	Regional population (Fatal cancers/y of operation)
Reference facility	4E-6 (2E-6)	2E-3 (8E-4)

(a)The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

REFERENCES

Co83 Corbit C. D., Herrington W. N., Higby D. P., Stout L. A., and Corley J. P., Background Information on Sources of Low-level Radionuclide Emissions to Air, PNL-4670, Prepared for EPA under U.S. DOE Contract by Battelle Memorial Institute, September 1983.

EPA79 Environmental Protection Agency, Radiological Impact Caused by Emissions of Radionuclides into Air in the United States, Preliminary Report, EPA 520/7-79-006, August 1979.

3.5 Other NRC Licensees (Co83)

This section includes NRC licensed laboratories, low-level waste disposal sites, and NRC-licensed mineral and metal processing facilities.

3.5.1 General Description

Laboratories

NRC-licensed laboratories include test, research, and development laboratories in industry, government agencies, and academic and research institutions. Approximately 700 laboratories are licensed by Agreement States to handle radioisotopes in an unsealed form. It is assumed that an equal number of NRC licensees handle unsealed radioisotopes, resulting in a total number of about 1,400 laboratories that are possible sources of low-level radioactive airborne emissions.

Waste Disposal Sites

There are six commercial low-level radioactive waste disposal sites, but only three of the sites, located at Barnwell, South Carolina, Beatty, Nevada, and Richland, Washington, are operational. The remaining three, located at Maxey Flats, Kentucky, Sheffield, Illinois, and West Valley, New York, are no longer operational.

The operational sites accept low-level radioactive wastes in a stabilized form, but not special nuclear materials, transuranics, and spent reactor fuels. Wastes accepted for disposal by shallow-land burial must meet specific site acceptance criteria. The majority of these wastes come from three sources: power-reactor operations, laboratory research, and medical facilities.

Mineral and Metal Processing Facilities

Facilities which extract metals from thorium- and uranium-bearing ores are licensed by NRC or an Agreement State. Six facilities, located in California, Florida, Illinois, New Mexico, and Pennsylvania (2 facilities), are licensed by NRC, and four facilities, located in Alabama, Colorado, Oregon, and Tennessee, are licensed by Agreement States. At facilities licensed by NRC, columbium and tantalum followed by rare earth extraction processes are the principal sources of radioactive materials that require control under the present provisions of 10 CFR 40. Two of the State-licensed facilities use thorium in their manufacturing process and two process ore to recover rare earths and refractory metals, respectively.

3.5.2 Process Description

Laboratories

Laboratory facilities at a single site vary from a small multipurpose single laboratory up to 300 individual laboratories, located within several buildings, at a major university. The smaller testing laboratories tend to specialize in the limited use of radionuclides for one purpose, such as soil testing or weld testing. Both academic and industrial laboratories use byproduct materials in basic research and development; radioactively labeled chemicals are used to trace a metabolic or physical pathway through a system. Medical research laboratories conduct basic chemical and applied radionuclide research related to a broad spectrum of diseases and health problems. Government laboratories may use radionuclides for specific purposes, such as food and drug testing, water and air quality, and ocean and fisheries monitoring. Thus, the testing and industrial laboratories tend to use larger quantities but a more limited variety of radionuclides than academic and other research laboratories.

A wide variety of radionuclides are found in laboratory work; the most frequently encountered nuclides are tritium, carbon-14, xenon-133, iodine-125, and iodine-131. The annual usage of any one radionuclide rarely exceeds 10 Ci, and typically is less than 0.5 Ci.

Waste Disposal Sites

The disposal sites typically consist of a large fenced area of about 100 ha. Operations buildings for decontamination, maintenance, and waste preparation, are typically located at one end of the site.

Wastes are usually buried in the transport containers in which they arrive at the site which minimizes radionuclide emissions to the air.

Mineral and Metal Processing Facilities

In general, most Agreement State and NRC licensed facilities are processing uranium- and thorium-bearing ores for either refractory metals, their oxides (zirconium, columbium/niobium, tantalum and hafnium) or for rare earths (cerium, praesodymium, neodymium, dysprosium, ytterbium, etc.). Thorium is being used in licensed facilities to manufacture welding rods and to cast machine parts.

The industrial processes used in licensed facilities may vary from wet chemical and solvent extraction to high temperature sintering and smelting. Raw ore storage, as well as sludge lagoons, drying beds, or other waste storage facilities, may also be sources of radon and thoron emissions.

3.5.3 Control Technology

Laboratories

The primary airborne emission controls employed by laboratories are HEPA filters installed in fume hoods, hot cells, and glove boxes. Laboratories which use one radionuclide predominately will frequently have specific controls for that nuclide, such as activated charcoal traps for xenon and iodine removal.

A catalytic recombiner followed by moisture removal is the principal technology for removal of gaseous tritium from airborne effluent streams. Chemical scrubbers may be used for removal of carbon-14.

Waste Disposal Sites

Currently, the operating burial sites use compacted soil covering to contain radioactive materials placed in the trenches. Despite having up to 2.4 m of soil cover, some radionuclides may permeate through the cover and enter the atmosphere. These low-level releases may be in various chemical or physical forms. No emission controls, beyond use of overburden, are currently used to minimize such releases.

Mineral and Metal Processing Facilities

Information on controls to reduce airborne emissions of radionuclides from NRC licensed facilities processing uranium- and thorium-bearing ores is not available.

3.5.4 Radionuclide Emissions

Laboratories

Data for 168 laboratories, including industrial, academic, government, medical, and engineering, were obtained from two surveys of byproduct users. Table 3.5-1 is a summary of the annual airborne releases reported by these facilities. For purposes of population exposure calculations, these emissions can be assumed to be at ground level.

Waste Disposal Sites

Radionuclide emissions from a nonoperational low-level waste disposal are summarized in Table 3.5-2. To reduce subsurface migration of radionuclides at this facility, the groundwater is pumped from sump wells in the trenches to an evaporator. The water is evaporated and the vapor is exhausted from an unfiltered 10-m stack. As can be seen in Table 3.5-2, the primary radionuclide of interest is tritium, which is emitted from the trenchwater evaporation system.

No data on operational sites were available.

Table 3.5-1. Radionuclide emissions from laboratories (Co83)

Number of facilities	Radionuclide	Emissions (Ci/y)			
		Minimum	Average	Maximum	Total
103	Tritium	0	2.8E-1	2.5E+1	2.9E+1
45	Carbon-14	0	6.9E-3	1.1E-1	3.1E-1
9	Krypton-85	0	1.6E-1	1.4	1.4
35	Iodine-125	0	4.0E-3	4.2E-2	1.4E-1
35	Iodine-131	0	3.0E-4	5.9E-3	1.1E-2
20	Xenon-133	0	8.0E-1	1.0E+1	1.6E+1
	All				4.7E+1

Table 3.5-2. Radionuclide emissions from a nonoperational low-level waste disposal site (Co83)

Radionuclide	Emissions (Ci/y)	
	Trenches	Evaporator
Tritium	8E+1	6E+3
Carbon-14	5	--
Cobalt-58	--	1.9E-4
Cobalt-60	--	5.8E-4
Strontium-90	--	4.6E-4
Cesium-134	--	2.1E-4
Cesium-137	--	8.3E-3
Plutonium-238	--	1.1E-4
Plutonium-239	--	2.0E-6

Mineral and Metal Processing Facilities

The NRC-licensed ore processing facilities are not required to report airborne radionuclide emissions. States having licensed facilities uniformly report that airborne radionuclide levels are well below values that require reporting. The limited data available indicate some elevated radon levels in the immediate vicinity of sludge lagoons; any effect on off-site radon levels was not obvious.

3.5.5 Health Impact from Other NRC Licensed Facilities

The emission rates listed in Tables 3.5-1 and 3.5-2 are quite low except for tritium released from the low-level waste disposal site. However, the whole body dose due to tritium released at this site is estimated to be less than 10 mrem/y for nearby individuals. Dose estimates for other radionuclides released from laboratories and the low-level waste disposal site are less than 1 mrem/y to nearby individuals. The limited data from NRC licensed ore processing facilities indicate that off-site radon levels are within the range of radon background concentrations.

3.5.6 Existing Emission Standards

Laboratories, low-level waste disposal sites, and uranium and thorium ore processing facilities licensed by NRC or by Agreement States are subject to the requirements of 10 CFR 20, Appendix B, Table II.

REFERENCES

Co83 Corbit C. D., Herrington W. N., Higby D. P., Stout L. A., and Corley J. P., Background Information on Sources of Low-level Radionuclide Emissions to Air, PNL-4670, Prepared for EPA under U.S. DOE Contract by Battelle Memorial Institute, September 1983.

3.6 Department of Defense Facilities

3.6A Armed Forces Radiobiology Research Institute (AFRRI)

3.6A.1 General Description

The Armed Forces Radiobiology Research Institute (AFRRI) operates a TRIGA Mark-F pool-type thermal research reactor, and a linear accelerator (linac) in support of Department of Defense radiation research. Most of this research involves studies of medical effects of nuclear radiation and the effects of transient radiation on electronics and other equipment.

The AFRRI reactor is licensed by the NRC to operate at steady-state power levels up to 1.0 MW (thermal). This reactor is also capable of pulse operations, and can produce a 10 msec pulse of about 2500 MW (thermal) at peak power.

AFRRI's linac typically operates in the 18 to 20 MeV energy range but is capable of operating at energies up to 30 MeV.

AFRRI is located on the grounds of the National Naval Medical Center in Bethesda, Maryland, approximately 20 kilometers northwest of Washington, D.C.

3.6A.2 Process Description

The AFRRI reactor and accelerator are used for Department of Defense radiation research. This research includes medical effects of nuclear radiation, radiobiology, and radioisotope production. AFRRI facilities have also been used to support Federal criminal investigations, studies of transient radiation effects on electronics, and artifact analysis (Sh81).

The reactor core, which is cooled by natural convection, is located under about 5 m of water, and is movable laterally within an open cloverleaf-shaped pool. Pool dimensions are 4.2 m across the major lobes, 3.9 m across the minor lobes, and 5.8 m deep.

Exposure facilities available to users include two separate exposure rooms, a pneumatic tube transfer system, the pool itself, and an in-core experiment tube.

Reactor fuel is 8.5 weight percent uranium which has been enriched to 20 percent uranium-235.

3.6A.3 Control Technology

Emissions from the AFRRI reactor and accelerator are released to the atmosphere through a common stack atop the AFRRI building.

Particulate emissions are controlled by a roughing filter, prefilter, and HEPA filter

3.6A.4 Radionuclide Emissions Measurements

Annual airborne radionuclide emissions for AFRRI are shown in Table 3.6A-1. These figures represent average annual emissions for 1981 and 1982 taken from the annual report to the NRC.

Table 3.6A-1. Radionuclide emissions from the Armed Forces Radiobiology Research Institute

Source	Radionuclide	Emissions[(a)] (Ci/y)
AFRRI stack	Argon-41	1.3
AFRRI stack	Nitrogen-13, and Oxygen-15	3.5E-2

(a)Average annual emissions for 1981 and 1982.

3.6A.5 Health Impact Assessment of AFRRI

The estimated annual radiation doses resulting from radionuclide emissions from AFRRI are listed in Table 3.6A-2. The distance from the AFRRI facility to the nearest residence is approximately 200 meters. These estimates are for a suburban site with a regional population of 2.5E+6 (Reference Site B). The nearby individuals are located 500 meters from the AFRRI facility for purposes of dose estimation.

Table 3.6A-3 lists the estimated lifetime risks to the nearby individuals and the number of fatal cancers per year to the regional population from these doses. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I.

3.6A.6 Existing Emission Standards and Air Pollution Controls

The AFRRI reactor is licensed by NRC and is therefore subject to the emission requirements of 10 CFR 20, Appendix B, Table II, which limits air emissions to unrestricted areas. For argon-41, the isotope responsible for all of the dose, this limit is 4×10^{-8} microcuries per milliliter above background.

Table 3.6A-2. Radiation dose rates from radionuclide emissions from the Armed Forces Radiobiology Research Institute

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Average of all organs	4.8E-3	1.7E-3

Table 3.6A-3. Fatal cancer risks due to radionuclide emissions from the Armed Forces Radiobiology Research Institute[a]

Source	Lifetime risk to nearby individuals		Regional population (Fatal cancers/y of operation)	
AFRRI Stack	9E-8	(4E-8)	5E-7	(2E-7)

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

3.6A.7 Supplemental Control Technology

There is no demonstrated treatment technology for control of emissions of argon-41 from reactors. Reduction of these emissions is best accomplished by work practice controls; i.e., reducing reactor operating time.

REFERENCES

Sh81 Sholtis J. A. and Moore M. L., Reactor Facility, Armed Forces Radiobiology Research Institute, AFRRI Technical Report TR81-2, AFRRI, Bethesda, Md., 1981.

3.6B U.S. Army Facilities

3.6B.1 General Description

The U.S. Army Test and Evaluation Command operates two reactors: the Army Pulse Radiation Facility (APRF) at Aberdeen Proving Ground, Maryland, and the Fast Burst Reactor (FBR) at White Sands Missile Range, New Mexico. These reactors are very similar in design and are used to support Army and other Department of Defense studies in nuclear radiation effects.

3.6B.2 Process Description

Both Army reactors are bare, unreflected, unmoderated, and fueled with enriched uranium. These reactors are capable of self-limiting, super-prompt-critical pulse operations as well as steady-state operations at power levels up to 10 kW (Aab82, AMT81). Operating information for the APRF and FBR for 1981 is summarized in Table 3.6B-1. The reactors are used primarily by DOD and defense contractors to study nuclear weapons effects on electronics and other DOD related equipment.

The White Sands FBR is the principal source of radioactive airborne emissions from Army reactors. At the FBR, concrete structures around the reactor reflect and thus lower the energy of neutrons streaming from the reactor. These low energy neutrons produce airborne radioactivity in the reactor building by neutron activation of stable argon-40 in air. Concrete structures at the APRF are farther from the reactor; hence, much less (essentially zero) argon-41 is produced at this facility (Aab82).

Table 3.6B-1. Number and modes of operations at Army Reactor Facilities, 1981 (Aab82, AMT81)

Type of operation	Number of operations	
	APRF	FBR
Pulse	211	252
Steady State	233	159
Unscheduled Terminations	-	8
Total	444	419

3.6B.3 Control Technology

Air exhausted from U.S. Army reactor facilities is passed through HEPA filters before release to the atmosphere.

3.6B.4 Radionuclide Emission Measurements

Radioactive emissions from Army reactors during 1976, 1978, and 1981 are listed in Table 3.6B-2. For the APRF, particulate releases are reported as gross beta concentrations only. All gaseous releases from the APRF were below the minimum detectable concentration of 3.0E-3 pCi/m^3.

Table 3.6B-2. Radionuclide emissions from Army Pulse Reactors

Radioactive material	Emissions (Ci/y)	
	APRF	FBR
Gross beta concentration:		
1976	2.8E-6	
1981	3.3E-5	
Argon-41:		
1976		11.7
1978		18.0
1981		13.3

Source: (De76, Aaa77, Aab82, AMT81).

3.6B.5 Health Impact Assessment from Army Pulse Reactors

The estimated annual radiation doses resulting from radionuclide emissions from the White Sands FBR are listed in Table 3.6B-3. The distances to the nearest offsite individuals at the APRF and FBR are approximately 1.6 km and 2.0 km, respectively. The predominant exposure pathway is that of air immersion. These estimates are for a sparsely populated southwestern location with a regional population of 3.6E+4 (Reference Site E).

Table 3.6B-4 lists the estimated lifetime risks to nearby individuals and the number of fatal cancers per year to the regional population from these doses.

Table 3.6B-3. Radiation dose rates from radionuclide emissions from the White Sands Fast Burst Reactor

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Endosteum	2.6E-2	9.2E-2
Spleen	2.6E-2	9.4E-2
Red Marrow	2.4E-2	8.6E-2
Muscle	2.4E-2	8.7E-2
Pulmonary	2.3E-2	8.2E-2

Table 3.6B-4. Fatal cancer risks due to radionuclide emissions from the White Sands Fast Burst Reactor(a)

Source	Lifetime risk to nearby individuals	Regional population (Fatal cancers/y of operation)
FBR	4E-7 (2E-7)	2E-5 (9E-6)

(a)The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

This assessment was made only for the White Sands FBR because nearly all measured radionuclide emissions from Army reactors originate at the FBR. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I.

3.6B.6 Existing Emission Standards

Airborne emissions from Army facilities are limited by the requirements of Army Regulation 385-11, Chapter 5, and Army Technical Manual 3-261. These requirements establish airborne concentration limits equivalent to NRC 10 CFR 20 concentrations, although the allowable averaging periods are more restrictive.

3.6B.7 Supplemental Control Technology

Emissions from Army pulse reactors consist mainly of argon-41, for which no demonstrated treatment technology exists. Reduction of argon-41 emissions are best controlled by work practice controls; e.g., reducing reactor operating time and reducing the amount of air subject to neutron irradiation by plugging air leaks into the reactor compartment.

REFERENCES

Aaa77	Aaserude R.A., Dickinson R. W., Dubyoski H. G., and Kazi A. H., APRF, Army Pulse Radiation Facility, Annual Operating Report, Aberdeen Proving Ground, Md., 1977
Aab82	Aaserude R.A., Dubyoski H. G., Harrell D.R. and Kazi A. H., Army Pulse Radiation Division Reactor, Annual Operating Report, Materiel Testing Directorate, Aberdeen Proving Ground, Md., 1982.
AMT81	Army Materiel Test and Evaluation Directorate, White Sands Missile Range Fast Burst Reactor, Annual Operating Report, Applied Sciences Division, White Sands Missile Range, N. M., 1981.
De76	De La Paz A. and Dressel R. W., White Sands Missile Range Fast Burst Reactor Facility, Annual Operating Report, Army Materiel Test and Evaluation Directorate, White Sands Missile Range, N.M., 1976.

3.6C U.S. Navy Facilities

3.6C.1 General Description

Airborne emissions of radionuclides from U.S. Navy facilities are due, almost entirely, to naval shipyards. Construction, overhaul, refueling, and maintenance of the 133 submarines and ships of the Navy's nuclear fleet are performed at nine naval shipyards at the following locations:

Mare Island Naval Shipyard, Vallejo, California
Electric Boat Division, General Dynamics, Groton, Connecticut
Pearl Harbor Naval Shipyard, Hawaii
Portsmouth Naval Shipyard, Kittery, Maine

Ingalls Shipbuilding Division, Pascagoula, Mississippi
U.S. Naval Station and Naval Shipyard, Charleston, S. C.
Newport News Shipbuilding and Drydock Co., Newport News, Va.
Norfolk Naval Shipyard, Portsmouth, Virginia
Puget Sound Naval Shipyard, Bremerton, Washington

3.6C.2 Process Description

Operations performed at naval shipyards include construction, startup testing, refueling, and maintenance of the pressurized water reactors that power the nuclear fleet. Radioactive wastes generated by these activities are processed and sealed at the shipyards and shipped to commercial waste disposal sites.

The primary sources of airborne radioactive emissions from naval shipyards are the support facilities that process and package radioactive waste materials for shipment to disposal sites. These facilities handle solid low-level radioactive wastes such as contaminated rags, paper, filters, ion exchange resins, and scrap materials.

During operation, shipboard nuclear reactors release small amounts of radioactivity (carbon-14) into the atmosphere; however, most of this is released at sea, beyond 12 miles from shore (R182).

3.6C.3 Control Technology

All air exhausted from radiological support facilities at naval shipyards is passed through HEPA filters and monitored during discharge. A comparison of airborne activity measurements in shipyards with radioactivity concentrations in ambient air indicates that air exhausted from these facilities actually contains less activity than the intake air (R182).

3.6C.4 Radionuclide Emission Measurements

Monitoring of effluents from nuclear naval shipyards began in 1963. To date, this monitoring has shown no concentration of airborne effluents in excess of naturally occurring background levels (EPA77).

Results of emission measurements taken at Puget Sound Naval Shipyard in 1974 are shown in Table 3.6C-1. These measurements showed that the tritium concentration was below the minimum detectable level of 1.0 pCi/l, and that the level of krypton-85 was within average background levels (EPA77).

Table 3.6C-1. Radionuclide emissions at Puget Sound Naval Shipyard, 1974

Source	Radionuclide	Emissions (pCi/l)
West of Radiological Support Building	Krypton-85	17.4 ± 10%
Radiological Support Building	Tritium	0.4 ± 50%
Radiological Support Building	Tritium	0.3 ± 66%

Radionuclide emissions from all naval shipyards were 0.41 Ci/y for argon-41, 0.21 Ci/y for xenon-133, and 0.25 Ci/y for xenon-135; all other radionuclide emissions were equal to or less than 0.1 Ci/y (Co83).

3.6C.5 Reference Facility

The typical nuclear shipyard processes, packages, and ships approximately 85 cubic meters of radioactive solid waste for disposal annually. The average activity of this material is approximately 6.3 curies. Waste packaging is performed in an enclosed facility, exhaust from which is passed through HEPA filters before release to the atmosphere. Air is exhausted from the radiological support facility at a height of about five meters.

Estimated radioactive emissions from the reference naval shipyard are listed in Table 3.6C-2. These are conservative, worst-case estimates used by the Navy in environmental pathways analysis, and are higher than any measurements made in the past five years at any shipyard (Ri82).

3.6C.6 Health Impact Assessment of the Reference Facility

The estimated annual radiation doses resulting from radionuclide emissions from the reference shipyard are listed in Table 3.6C-3. The distance to the nearest offsite individual is approximately one km. The predominant exposure pathway is that of ground shine. These estimates are for a suburban site with a regional population of 2.5E+6 (Reference Site B).

Table 3.6C-2. Radionuclide emissions from the reference facility (Ri82)

Radionuclide	Emissions (Ci/y)
Argon-41	4.1E-1
Cobalt-60	1.0E-3
Tritium	1.0E-3
Carbon-14	1.0E-1
Krypton-83m	2.0E-2
Krypton-85m	2.4E-2
Krypton-85	1.0E-3
Krypton-87	5.0E-2
Krypton-88	2.0E-2
Xenon-131m	5.0E-3
Xenon-133m	1.0E-2
Xenon-133	2.1E-1
Xenon-135	2.5E-1

Table 3.6C-4 presents estimates of the lifetime risks to nearby individuals and the number of fatal cancers per year to the regional population from these doses. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I.

3.6C.7 Total Health Impact of U.S. Nuclear Naval Shipyards

The total health impact caused by all naval shipyards may be estimated from Table 3.6C-4 and the ratio of the capacity of the reference shipyard to the capacity of all nuclear naval shipyards.

Table 3.6C-3. Radiation dose rates from radionuclide emissions from the reference facility

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Average of all organs	1.6E-2	8.7E-2

Table 3.6C-4. Fatal cancer risks due to radionuclide emissions from the reference facility[a]

Source	Lifetime risk to nearby individuals		Regional population (Fatal cancers/y of operation)	
Nuclear naval shipyard	3E-7	(1E-7)	2E-5	(1E-5)

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

3.6C.8 Existing Emission Standards

Because Navy facilities are not licensed by NRC, they are not subject to radionuclide emission standards.

3.6C.9 Supplemental Control Technology

There is no demonstrated treatment technology for controlling emissions of krypton-85 or other radioactive noble gases from radiological support facilities.

Tritium emissions could be controlled by using a catalytic recombiner; however, this would be impractical considering the extremely low levels of tritium emitted from radiological support facilities.

REFERENCES

Co83	Corbit C. D., Herrington W. N., Higby D. P., Stout L. A., and Corley J. P., Background Information on Sources of Low-level Radionuclide Emissions to Air, PNL-4670, Prepared for EPA under U.S. DOE Contract by Battelle Memorial Institute, September 1983.
EPA77	Environmental Protection Agency, Radiological Survey of Puget Sound Naval Shipyard, Bremerton, Washington, and Environs, EPA-520/5-77-001, Office of Radiation Programs, EPA, Washington, D.C., 1977.
Ri82	Rice P. D., Sjoblom G. L., Steele J. M. and Harvey B. F., Environmental Monitoring and Disposal of Radioactive Wastes from U.S. Naval Nuclear-Powered Ships and Their Support Facilities, Report NT-82-1, Naval Nuclear Propulsion Program, Department of the Navy, Washington, D.C., 1982.

Chapter 4: COAL-FIRED UTILITY AND INDUSTRIAL BOILERS

4.0 Introduction

Large coal-fired boilers are used to generate electricity for public and industrial use and to provide process steam, process hot water, and space heat. For the purposes of this report, boilers used in the utility industry are designated utility boilers and those used to generate process steam/hot water, space heat, or electricity for in-house use are designated industrial boilers.

From 1974 to 1977, about 18 percent of the energy needs in the United States were met by burning coal; 66 percent to generate electricity, and about 32 percent for industrial uses. More than 600 million tons are burned each year in utility and industrial boilers (EPA80).

Coal contains mineral matter including trace quantities of naturally-occurring radionuclides. Uranium-238 and thorium-232 and their decay products are the radionuclides of interest with respect to air emissions and potential health effects. Data showing typical uranium and thorium concentrations in coal are presented in Table 4.0-1. The data for "All Coals," given at the end of Table 4.0-1, represent more than 5,000 coal samples from the major coal producing regions of the United States. DOE has analyzed uranium concentrations in more than 3,700 coal samples and reports concentrations ranging from less than 2 to 130 parts per million (ppm). These data (see Table 4.0-2) show about 71 percent of all coals have uranium-238 concentrations less than or equal to 2.0 ppm, and that 98 percent of all coals have uranium-238 concentrations of 10 ppm or less. Coal also contains the decay products of uranium-238 and thorium-232 (see Tables 4.0-3 and 4.0-4) in secular equilibrium (Wa82). Thus, the specific activity of each decay product is equal to the specific activity of its uranium or thorium parent.

As coal is burned, the minerals in the coal melt and then condense into a glass-like ash; the quantity depending on the mineral content of the coal. A portion of the ash settles to the bottom of the boiler (bottom ash) and a portion enters the flue gas stream (fly ash). The partitioning of ash between bottom and fly ash depends on the type of

Table 4.0-1. Typical uranium and thorium concentrations in coal

Region/ Coal Rank	Uranium		Thorium		Reference
	Range (ppm)	Geometric mean (ppm)	Range (ppm)	Geometric mean (ppm)	
Pennsylvania					
Anthracite	0.3 - 25	1.2	2.8 - 14	4.7	Sw76
Appalachian					
Bituminous	<0.2 - 11	1.0	2 - 48	2.8	Sw76
NR	0.4 - 3	1.3	1.8 - 9	4.0	IGS77
Bituminous	NR	1.1	NR	2.0	SRI77
Bituminous	0.1 - 19	1.2	NR	3.1	Zu79
Illinois Basin					
NR	0.3 - 5	1.3	0.7 - 5	1.9	IGS77
Bituminous	0.2 - 43	1.4	<3 - 79	1.6	Sw76
Bituminous	0.2 - 59	1.7	<0.1 - 79	3	Zu79
Northern Great Plains					
Bituminous-Subbituminous	<0.2 - 3	0.7	<2 - 8	2.4	Sw76
Subbituminous	<0.1 - 16	1.0	0.1 - 42	3.2	Zu79
Lignite	0.2 - 13	1.2	0.3 - 14	2.3	Zu79
Western					
NR	0.3 - 3	1.0	0.6 - 6	2.3	IGS77
Rocky Mountain					
Bituminous-Subbituminous	0.2 - 24	0.8	<3 - 35	2.0	Sw76
Subbituminous	0.1 - 76	1.9	0.1 - 54	4.4	Zu79
Bituminous	0.1 - 42	1.4	<0.2 - 18	3.0	Zu79
All Coals	<0.1 - 76	1.3	<0.1 - 79	3.2	Zu79

Note: 1 ppm uranium-238 is equivalent to 0.33 pCi/g of coal.
1 ppm thorium-232 is equivalent to 0.11 pCi/g of coal.
NR Not reported.

boiler (see Section 4.1, Utility Boilers). The ash contains the radionuclides originally present in the coal. Measurements of radionuclides in bottom and fly ash show that certain radionuclides are enriched in the fly ash relative to the bottom ash, particularly in the respirable (less than or equal to 10 micrometers) fraction of the fly ash (Sm80). The fraction of fly ash that is not captured by the emission control equipment is released to the atmosphere. Thus, the quantitiy of radionuclides released depends on the uranium and thorium content of the coal, furnace design, enrichment factors for fly ash, and the efficiency of the effluent control system for particulates.

Radionuclides that are contained in fly ash exhausted to the environment may expose people in several ways: they may be inhaled; they may settle onto the ground and expose people nearby; and they may settle onto crops or be taken up through the roots of crops and then be eaten. Humans exposed to radiation by any of these means have an increased risk of cancer and other health effects.

Table 4.0-2. Uranium concentrations and distributions in coal

Uranium concentration (ppm)	Number of coals analyzed	Percent of coals within uranium concentration range	Cumulative percent of coals equal or less than uranium concentration range
Less than 2	2669	71.5	71.5
2 - 4	666	17.9	89.4
4 - 6	207	5.5	94.9
6 - 8	67	1.8	96.7
8 - 10	39	1.0	97.8
10 - 12	26	0.7	98.5
12 - 14	17	0.5	98.9
14 - 16	12	0.3	99.2
16 - 18	7	0.2	99.4
18 - 20	5	0.1	99.6
20 - 30	9	0.2	99.8
30 - 60	5	0.1	99.9
60 - 130	2	0.05	100.0

Source: Fa79.

Table 4.0-3. Major decay products of uranium-238

Radionuclide	Half-life	Principal radiation (Mev)		
		Alpha	Beta (max)	Gamma
Uranium-238	$4.5x10^9$ y	4.20		
Thorium-234	24 d		0.191	0.093
Protactinium-234m	1.2 m		2.29	1.001
Uranium-234	$2.5x10^5$ y	4.77		
Thorium-230	$8.0x10^4$ y	4.68		
Radium-226	$1.6x10^3$ y	4.78		0.186
Radon-222	3.8 d	5.49		
Polonium-218	3.1 m	6.00		
Lead-214	27 m		0.65	0.352
Bismuth-214	20 m		1.51	0.609
Polonium-214	$1.6x10^{-4}$ s	7.69		
Lead-210	22 y		0.015	0.047
Bismuth-210	5.0 d		1.160	
Polonium-210	138 d	5.31		

Source: Le67.

y = years d = days h = hours m = minutes s = seconds

Table 4.0-4. Major decay products of thorium-232

Radionuclide	Half-life	Principal radiation (Mev)		
		Alpha	Beta	Gamma
Thorium-232	$1.4x10^{10}$ y	4.01		
Radium-228	6.7 y		0.055	
Actinium-228	6.1 h		1.11	0.908
Thorium-228	1.9 y	5.43		0.084
Radium-224	3.6 d	5.68		0.241
Radon-220	55 s	6.29		
Polonium-216	0.15 s	6.78		
Lead-212	10 h		0.589	0.239
Bismuth-212	60 m		2.25	0.727
Polonium-212	$3.1x10^{-7}$ s	8.78		
Thallium-208	3.1 m		1.80	2.614

Source: Le67.

y = years d = days h = hours m = minutes s = seconds

REFERENCES

EPA80 Environmental Protection Agency, Fossil Fuel-Fired Industrial Boilers--Background Information for Proposed Standards, Chapters 3-5, Research Triangle Park, N.C., June 1980.

Fa79 Facer J.F., Jr., 1979, Uranium in Coal, U.S. Department of Energy Report, GJBX-56(79), Washington, D.C.

IGS77 Illinois State Geological Survey, Trace Elements in Coal: Occurrence and Distribution, NTIS Report No. PB-270-922, June 1977.

Le67 Lederer C.M., Hollander J.M. and I. Perlman, Table of Isotopes, Sixth Edition, John Wiley and Sons, New York, 1967.

Sm80 Smith R.D., The Trace Element Chemistry of Coal during Combustion and the Emissions from Coal-Fired Plants, Progress in Energy and Combustion, Science 6, 53-119, 1980.

SRI77 Stanford Research Institute, Potential Radioactive Pollutants Resulting from Expanded Energy Programs, NTIS Report No. PB-272-519, August 1977.

Sw76 Swanson V.E., et al., Collection, Chemical Analysis, and Evaluation of Coal Samples in 1975, Department of the Interior, Geological Survey, Open File Report 76-468, 1976.

Wa82 Wagner P. and N.R. Greiner, Third Annual Report, Radioactive Emissions from Coal Production and Utilization, October 1, 1980-September 30, 1981, LA-9359-PR, Los Alamos National Laboratory, Los Alamos, N.M., 1982.

Zu79 Zubovic P., et al., Assessment of the Chemical Composition of Coal Resources, USGS Expert Paper Presented at the United National Symposium on World Coal Prospects, Katowice, Poland, April 15-23, 1979.

4.1 Utility Boilers

4.1.1 General Description

At the end of 1979, the total capacity of U.S. electric utility generating units was 593 gigawatts (GW) (TRI79a). Table 4.1-1 lists the capacity of the utility industry for 1979 and projections for 1985. Coal-fired steam electic power units accounted for 38 percent of total capacity and 49 percent of total energy generation in 1979. Coal-fired steam electric plants will account for 40 percent of total generating capacity and for 49 percent of total power generation by 1985.

Power plants are designed and operated to serve three load classes: (a) base-load plants, which operate near full capacity most of the time (or are dispatched to operate in the most efficient region of the heat rate curve); (b) intermediate-load (or cycling) plants, which operate at varying levels of capacity each day (about 40 percent utilization on an average annual basis); and (c) peaking plants, which operate only a few hours per day (about 700-800 hours per year). Fossil-fueled steam electric plants now dominate base-load and intermediate-load service.

The average national capacity factor dropped from 55 percent in 1970 to 47 percent in 1978; the average base-load capacity factor, from 68 percent in 1970 to 64 percent in 1978. The average capacity factor for cycling units remained almost constant over this period (DOE79).

Capacity and Age of Coal-Fired Steam Units

There were 1,224 coal-fired units with a total generating capacity of 225 GW on line in 1979 (the base year). The distribution of these units by capacity and age is shown in Table 4.1-2. About 50 percent of coal-fired capacity is less than 10 years old. Most of the units with capacities of 26 to 100 MW are between 25 and 29 years old, while those with capacities of 101 to 300 MW are between 20 and 24 years old. Units larger than 300 MW are 5 to 9 years old. About 21 percent of the coal-fired units account for 50 percent of total generating capacity.

By 1985 there will be 1,360 coal-fired units on line with a capacity of 307 GW, an increase over the base year of approximately 36 percent (TRI79a). In 1985, capacity of units less than 5 years old will account for 22 percent of the total projected capacity and for about 10 percent of the total number of units.

The retirement rates for fossil units of a given capacity and size will significantly affect system composition by 1985. Seventy-nine coal units are scheduled for retirement by 1985. No retirements are scheduled for units greater than 300 MW in capacity.

Table 4.1-1. U.S. electric utility generating capacity
(Gigawatts)

Generating technology	1979 (GW)	1979 (% of total)	1985 (GW)	1985 (% of total)
Coal-fired steam electric	225.1	(38.0)	306.0	(40.0)
Oil-fired steam electric	101.4	(17.1)	112.5	(14.7)
Gas-fired steam electric	59.9	(10.1)	39.5	(5.2)
Combined-cycle plants	2.5	(.4)	5.3	(.7)
Combustion gas-turbine, internal combustion	76.9	(13.0)	102.4	(13.4)
Nuclear	51.1	(8.6)	112.6	(14.7)
Hydroelectric	73.3	(12.4)	77.9	(10.1)
Geothermal	.9	(.2)	1.9	(.2)
Others	2.0	(.3)	7.9	(1.0)
Total	593.1	(100.1)*	766.0	(100.0)

Source: (TRI79a).
*Percentages do not add to 100.0 due to rounding.

Coal consumption by the electric utilities is expected to increase from 438 million metric tons in 1979 to 633 million metric tons in 1985 (TRI79b, DOE74).

4.1.2 Process Description

In the typical power plant, a mixture of finely ground coal and air is blown into a combustion chamber at the base of the boiler and ignited as it passes through a burner. In the upper portion of the boiler (above the combustion zone), boiler feedwater is simultaneously pumped through a series of metal tube banks. The heat contained in combustion gases is transferred to the feedwater which ultimately leaves the boiler as saturated steam. This high-temperature, high-pressure steam (540° C at 2.46 kgs/cm^2) is used to drive a turbine that, in turn, drives an electric generator. Vapor leaving the turbine is fed to a cooling system that extracts residual heat and recycles condensate water back to the boiler.

Coal combustion produces an ash that is either retained within the boiler (bottom ash) or carried out of the boiler with combustion

Table 4.1-2. Distribution of U.S. coal-fired units by age and capacity, 1979

Age	Capacity of coal-fired units									
	0.03-0.1 GW		0.1-0.3 GW		0.3-0.6 GW		Greater than 0.6 GW		Totals[a]	
	(Units)	(GW)	(Units)	(GW)	(Units)	(GW)	(Units)	(GW)	(Units)	(GW)
0-4	6	0.5	21	4.6	54	24.8	30	22.4	120	52.4
5-9	9	0.5	22	4.2	44	20.2	42	33.8	139	58.9
10-14	19	1.3	42	8.5	40	18.0	12	8.7	132	36.8
15-19	26	1.6	73	13.8	18	7.1	2	1.3	140	24.2
20-24	36	2.3	130	22.3	4	1.3	0	0	204	26.3
25-29	104	7.1	83	11.3	0	0	0	0	255	19.3
30-34	60	3.4	4	0.5	0	0	0	0	121	4.5
35-39	32	1.8	0	0	0	0	0	0	58	2.0
40-44	3	0.1	0	0	0	0	0	0	24	0.3
45-49	2	0.1	0	0	0	0	0	0	7	0.1
50-54	2	0.1	0	0	0	0	0	0	16	0.2
55-59	0	0	0	0	0	0	0	0	6	0.1
60	0	0	0	0	0	0	0	0	2	0.01
Total	299	18.8	375	65.2	160	71.4	86	66.2	1224	225.1

Source: (TRI79a).

(a)Totals include an additional 304 units having a total capacity of 3.5 GW in the 0-0.03 GW range.

gases (fly ash). A portion of the fly ash is removed from the flue gas before it is released to the atmosphere by a particulate control system.

Fly ash, bottom ash, slag, and scrubber sludges are removed from the boiler and accumulate in solid waste piles adjacent to the plant. These waste piles may range in area from 80 to 100 hectares for a single 550 MW unit. In 1977 about 50 M metric tons of ash were generated by coal-fired electric generating plants in the United States. Some of the ash is stored near or on the station site; some is returned to a coal mine for disposal; and some can be used.

Furnace Design

The distribution of particulates between bottom ash and fly ash depends on the firing method, the ash fusion temperature of the coal, and the type of boiler bottom (wet or dry).

Fuel-firing equipment (Table 4.1-3) can be divided into three general categories: stoker furnace (dry bottom), composed of spreader or non-spreader types; cyclone furnace (wet bottom); and pulverized-coal furnace (dry or wet bottom).

Table 4.1-3. Classification of coal-fired units by firing method and type of boiler bottom, 1976

	Number of units	Generating capacity (MW)	Percent of total
Stoker (all dry bottom)	165	2,015	(1.0)
Cyclone (all wet bottom)	94	24,449	(12.0)
Pulverized (wet bottom)	135	16,440	(8.0)
Pulverized (dry bottom)	837	161,092	(79.0)
Total	1231	203,996	

Source: (DOE76).

Note: Total number of units and generating capacity in Table 4.1-3 are slightly different from previously-mentioned figures because of unit retirements, derating, etc.

Stoker-Fired Furnaces. Stoker furnaces are usually small, old boilers ranging in capacity from 7.3 to 73 MW (thermal). Of the boilers designed for coal and sold from 1965 to 1973, none exceeded 143 MW(t); 63 percent were stoker-fired; 41 percent, spreader stoker; 9 percent, underfeed stoker; and 13 percent, overfeed stoker. Stokers require about 3.3 kg of coal per kilowatt-hour and are less efficient than units handling pulverized coal. Stoker-fired units produce relatively coarse fly ash. Sixty-five percent of the total ash in spreader stokers is fly ash.

Cyclone Furnaces. Crushed coal is burned in a high-temperature combustion chamber called a cyclone. The high temperatures in the furnace lead to the formation of a molten slag which drains continuously into a quenching tank. Roughly 80 percent of the ash is retained as bottom ash. Only 9 percent of the coal-fired utility boiler capacity in 1974 was of the cyclone type, and no boilers of this kind have been ordered by utilities in the past seven years (Coc75).

Pulverized-coal Furnaces. Coal is pulverized to a fine powder (approximately 200 mesh) and injected into the combustion zone in an intimate mixture with air. Pulverized-coal furnaces are designed to remove bottom ash as either a solid (dry-bottom boiler), or as a molten slag (wet-bottom boiler).

The dry-bottom, pulverized-coal-fired boiler, in which the furnace temperature is kept low enough to prevent the ash from becoming molten, is now the most prevalent type of coal-burning unit in the utility sector. About 80 to 85 percent of the ash produced in the dry-bottom, pulverized-coal-fired boiler is fly ash. The remainder of the ash falls to the bottom of the furnace, where it is either transported dry or cooled with water and removed from the boiler as slurry to an ash-settling pond.

Mode of Operation

The new units have historically been used for base load generation; cycling capacity has been obtained by downgrading the older, less efficient, base load equipment as more replacement capacity comes on line.

In 1979, the average capacity factor(1) for coal-fired units operating in the base load mode was 65 percent; for units operating in a cycling mode, 42 percent (TRI79a). The availability(2) of a coal-fired unit generally declines with increasing generating capacity. Generating units with capacities of less than 400 MW have average availabilities of more than 85 percent; those with capacities of more than 500 MW, only 74 to 76 percent (An77). The operating mode affects the heat rate of the plant; for example, changing the capacity factor from 42 to 70 percent changed the heat rate from 12.3 to 9.2 MJ/kWh.

4.1.3 Control Technology

Four types of conventional control devices are commonly used for particulate control in utility boilers: electrostatic precipitators (ESPs), mechanical collectors, wet scrubbers, and fabric filters. Comprehensive evaluations of each control device have been given in several publications (Dea77, Deb79, St76, Cob77).

Selection of the particulate control device for a given unit is affected by many parameters, including boiler capacity and type, inlet loading, fly ash characteristics, inlet particle size distribution, applicable regulations, and characteristics of the control device itself. The location of particulate control devices with respect to SO_2 scrubber systems in a plant depends on the type of scrubbers (wet or dry) installed; these devices are located upstream of a wet scrubber system or downstream of a spray dryer system.

---

(1) Capacity factor equals the ratio of energy actually produced in a given period to the energy that would have been produced in the same period had the unit been operated continuously at its rated power.

(2) Availablity refers to the fraction of a year during which a unit is capable of providing electricity to the utility grid at its rated power after planned and forced outages have been accounted for.

ESPs with collection efficiencies of more than 99.8 percent have historically been the control device of choice for utility boilers. However, as a result of the growing use of low-sulfur western coals, wet scrubbers and fabric filters have increasingly been chosen.

Table 4.1-4 shows the distribution of control equipment in use in 1976 on coal-fired steam electric boilers (DOE76).

4.1.4 Radionuclide Emissions

The emission of radionuclides in the fly ash generated during combustion depends on the type of coal used; that is, its mineral content and the concentrations of uranium, thorium, and their decay products. Other factors influencing radionucide emissions include furnace design, capacity, capacity factor, heat rate, ash partitioning, enrichment factors, and emission control efficiency (Table 4.1-5). The distribution of ash between the bottom and fly ash depends on the firing method, coal, and furnace (dry bottom or wet bottom). For pulverized-coal, dry bottom units, 80-85 percent of the ash is fly ash.

Recent measurements have shown that trace elements, such as uranium, lead, and polonium, are partitioned unequally between bottom ash and fly ash (Be78, Wa82). Although the concentration mechanism is not fully understood, one explanation is that certain elements are preferentially concentrated on the particle surfaces, resulting in their depletion in the bottom ash and their enrichment in the fly ash (Sm80). The highest concentration of the trace elements in fly ash is found in particulates in the 0.5 to 10.0 micrometer diameter range, the size range that can be inhaled and deposited in the lung. These fine particles are less efficiently removed by particulate control devices than larger particles. Based on measured data, typical enrichment factors are: 2 for uranium, 1.5 for radium, 5 for lead and polonium, and 1 for all other radionuclides (EPA81).

Coal storage and waste piles at utility boiler sites are also potential sources of radon-222. Analyses of fugitive emission data from these piles indicate, however, that the radon-222 "exhalation rate" is less than that for soil, as reported by Beck (Be81).

Measured Radionuclide Emissions

EPA has measured radionuclide emissions at nine utility boilers. Summaries of emissions data from these studies are presented in Tables 4.1-6 and 4.1-7.

Table 4.1-4. Particulate emission control equipment by type of boiler, 1976

Control equipment	Stoker		Pulverized cyclone		Pulverized wet bottom	
	Capacity (GW)	Units	Capacity (GW)	Units	Capacity (GW)	Units
No control	0.7	76	3.9	18	4.5	66
Mechanical[a]	0.8	63	1.2	7	0.5	11
Wet scrubbers	-					-
Fabric filters	0.1	2	-			-
ESP	-		19.0	62	9.5	44
Combination[b]	0.4	24	0.4	7	2.0	14

Control equipment	Dry bottom		Total	
	Capacity (GW)	Units	Capacity (GW)	Units
No control	26.8	266	35.9	426
Mechanical[a]	2.4	50	4.9	131
Wet scrubbers	1.9	7	1.9	7
Fabric filters	0.8	3	0.9	5
ESP	110.1	374	138.5	480
Combination[b]	19.2	137	22.0	182

[a] Mechanical devices include cyclones and gravitational chambers.
[b] Combination refers to mechanical-electrostatic precipitators.
Source: (DOE76).

Table 4.1-5. Parameters affecting radionuclide emissions from coal-fired units

Parameter	Effect
Coal properties (heating value, mineral matter, moisture and sulfur content)	Radionuclide content of ash depends directly on the amounts of uranium, thorium, and their daughters contained in the coal, and the percentage of mineral matter in the coal.
Heat rate	Total particulate release is directly related to coal consumption, which in turn depends on heat rate.
Capacity	Total particulate emission is directly related to unit size.
Mode of operation (capacity factor)	Mode of operation affects capacity factor and heat rate, which in turn influences total particulate emissions.
Ash partitioning	Partitioning of ash between bottom and fly ash directly affects particulate emission rate.
Enrichment of radionuclides in fly ash	The enrichment of certain radionuclides in the fly ash relative to the bottom ash directly affects the radionuclide emission rate.
Type of control device	Rate of particulate release depends on the efficiency of control devices.

Table 4.1-6. Radionuclide emission rates (mCi/y) measured at selected coal-fired steam electric generating stations

Radionuclide	Sampling location[(a)]			
	M-1	M-2	M-3	M-4
Uranium-238	24	5.7	0.76	0.10
Uranium-234	24	7.2	0.81	0.10
Thorium-230	1.5	4.1	0.29	0.08
Radium-226	5.3	4.1	0.21	0.02
Lead-210	28	15	1.4	0.18
Polonium-210	68	14	1.1	0.16
Thorium-232	0.81	1.5	0.02	0.05
Thorium-228	0.72	1.7	0.30	0.05

Source: EPA80

(a) Sampling locations:

M-1 West North Central Station (874 MW).
M-2 East North Central Station (450 MW).
M-3 South Atlantic Station (125 MW).
M-4 Mountain Station (12.5 MW).

Table 4.1-7. Summary of radionuclide emission rates (mCi/y) measured at five coal-fired steam electric generating units

Radionuclide	Sampling location[(a)]				
	M-1	M-33	M-15	M-34	M-99
Uranium-238	120	14	2	1	0.06
Thorium-230	17	8.8	0.3	1	0.06
Radium-226	63	12	0.5	3	0.1
Polonium-210	1000	22	< 0.6	3	< 3.0
Lead-210	340	30	(b)	24	(b)
Thorium-232	8.5	8	0.1	1	0.06

Source: (Ro83).

(a) Sampling locations and particulate control devices used at each of the units are:

M-1 West North Central unit (874 MW gross); wet limestone scrubber.
M-33 South Central unit (593 MW gross); cold side ESP.
M-15 North Central unit (56 MW gross); mechanical collector followed by a wet venturi scrubber.
M-34 South Central unit (800 MW gross); cold side ESP and baghouse followed by a wet limestone scrubber.
M-99 North Central unit (75 MW gross); mechanical collector followed by an ESP.

(b) No lead-210 analysis was made on samples collected at these units.

Estimated Radionuclide Emissions Based on Particulate Emissions

An estimate of the radioactivity released by coal-fired utility boilers may be made by multiplying the particulate release rate (g/y) by the average concentration of radionuclides in fly ash (pCi/g). The concentration of radionuclides in fly ash depends on the concentrations of uranium-238 and thorium-232 and their decay products in the coal, the ash content of the coal, the partitioning between fly ash and bottom ash, and the enrichment factors for the radionuclides in the fly ash. Using typical values of 1.3 ppm uranium-238 and 3.2 ppm thorium-232 in coal (see Table 4.0-1), 7.6 percent ash in coal (IGS77), a partitioning factor of 0.8 for fly ash, enrichment factors of 2 for uranium and 1 for thorium, and the specific activities of uranium and thorium, the calculated values for uranium and thorium in fly ash are 11 pCi/g and 4 pCi/g, respectively. A measured value of 9 pCi/g of uranium-238 in fly ash was used for calculations in this chapter (Coa78). Values for the other radionuclides in the uranium and thorium series may be derived by applying enrichment factors of 1.5 for radium, 5 for lead and polonium, and 1 for all other radionuclides.

The particulate emission rate for all the coal-fired utility boilers in the United States has been estimated to be 0.9 million metric tons per year (RC83). Assuming 9 pCi U/g fly ash, this results in an annual emission rate of about 8 curies of uranium-238 for the industry.

4.1.5 Reference Facility

The annual emissions of radionuclides from coal-fired utility boilers cover a very large range because of the large range of coal properties, boiler parameters, and control efficiencies. In order to assess the health impact of these facilities, a reference coal-fired utility boiler was defined. The uranium-238 emission rate for the reference facility of 100 mCi/yr was selected on the basis of EPA's judgment as representative of the upper range of potential emissions (see Tables 4.1-6 and 4.1-7). Such emissions could be obtained from large well-controlled boilers burning coal with relatively high uranium content, or from large boilers with fewer controls burning coal of average or less than average uranium content.

The source term for the reference facility is defined in Table 4.1-8. The annual emissions for thorium, radium, lead, and polonium reflect the fly ash enrichment factors noted previously. The reference facility is assumed to have a stack height of 185 meters and a plume rise of 50 meters, typical of large utility boilers.

4.1.6 Health Impact Assessment of the Reference Utility Boiler

Because utility boilers may be located near large cites or at remote sites, the health impact of the reference facility was determined at four sites classified as urban, suburban, rural, and remote (see Table 4.1-9).

Table 4.1-8. Radionuclide emissions from the reference facility

Radionuclide	Emissions (Ci/y)
Uranium series	
Uranium-238	1.0E-1
Uranium-234	1.0E-1
Thorium-230	5.0E-2
Radium-226	7.5E-2
Radon-222	9.6E-1
Lead-210	2.5E-1
Polonium-210	2.5E-1
Thorium series	
Thorium-232	4.3E-2
Radium-228	6.5E-2
Actinium-228	4.3E-2
Thorium-228	4.3E-2
Radium-224	6.5E-2
Radon-220	8.3E-1
Lead-212	2.2E-1
Bismuth-212	4.3E-2
Thallium-208	4.3E-2

Table 4.1-9. Population distribution of the reference facility

Site	Population[a]
Urban	1.72E+7
Suburban	2.49E+6
Rural	5.89E+5
Remote	1.19E+4

[a] Number of people located within a radius of 80 km.

The estimated annual radiation doses from radionuclide emissions from the reference boiler at each of the generic sites are presented in Table 4.1-10.

Table 4.1-10. Radiation dose rates from radionuclide emissions from the reference utility boiler

Organ	Urban site: Nearby individuals (mrem/y)	Urban site: Regional population (person-rem/y)	Suburban site: Nearby individuals (mrem/y)	Suburban site: Regional population (person-rem/y)
Lung	9.9E-1	4.2E+3	1.3	3.9E+2
Red marrow	1.0E-1	3.3E+2	2.1E-1	4.3E+1
Kidney	1.0E-1	1.3E+2	2.3E-1	8.0E+1
Endosteum	1.2	4.6E+3	1.8	5.0E+2
Liver	5.0E-2	7.1E+1	1.4E-1	2.7E+1

Organ	Rural site: Nearby individuals (mrem/y)	Rural site: Regional population (person-rem/y)	Remote site: Nearby individuals (mrem/y)	Remote site: Regional population (person-rem/y)
Lung	1.7	1.1E+2	1.2	1.1
Red marrow	2.1	1.9E+1	1.4E-1	1.5E-1
Kidney	2.4	3.0E+1	8.6E-2	2.6E-2
Endosteum	4.7	1.4E+2	1.4	1.7
Liver	1.9	1.4E+1	6.4E-2	1.1E-1

Table 4.1-11 presents estimates of lifetime risks to nearby individuals and the number of fatal cancers to the regional population resulting from particulate doses at each of the generic sites for the reference unit. The urban site is a conservative selection, and estimates for this site represent an upper limit of the potential health impact to a regional population. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I.

4.1.7 Health Impact Assessment of Specific Utility Boilers

EPA surveyed emissions from five utility boilers located in areas similar to the generic rural site. The emission rates for these boilers are listed in Table 4.1-7. Using the generic rural site data and the actual emission rates measured by EPA, estimated annual radiation doses were calculated for nearby individuals and regional population (Tables 4.1-12 and 4.1-13).

Table 4.1-11. Fatal cancer risks from the reference facility[a]

Site	Lifetime risk to nearby individuals	Regional population (Fatal cancers/y of operation)
Urban	2E-6	1E-1
Suburban	4E-6 (3E-6)	1E-2
Rural	3E-5 (1E-5)	5E-3 (3E-3)
Remote	3E-6 (2E-6)	3E-5

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

Table 4.1-12. Radiation dose rates to nearby individuals from radionuclide emissions from five utility boilers

Organ	Nearby individuals (mrem/y)				
	M-1	M-33	M-15	M-34	M-99
Lung	8.8E-1	5.2E-1	1.5E-1	5.5E-2	1.1E-2
Red marrow	1.3E-1	3.9E-1	8.6E-3	7.1E-2	4.5E-3
Kidney	4.2	3.5E-1	5.5E-3	6.7E-2	1.3E-2
Endosteum	3.0	1.1	6.6E-2	1.9E-1	2.0E-2
Liver	1.7	3.2	4.5E-3	7.2E-2	6.5E-3

Table 4.1-13. Radiation dose rates to the regional population from radionuclide emissions from five utility boilers

Organ	Regional population (person-rem/y)				
	M-1	M-33	M-15	M-34	M-99
Lung	8.8E+1	2.6E+1	3.7	2.4	3.6E-1
Red marrow	1.3E+1	4.3	1.5E-1	5.8E-1	6.0E-2
Kidney	9.1E+1	3.6	1.1E-1	6.4E-1	3.1E-1
Endosteum	5.2E+1	4.0E+1	1.5	4.2	4.5E-1
Liver	2.2E+1	2.2	6.1E-2	5.4E-1	9.3E-2

Table 4.1-14 presents estimates of lifetime risks to nearby individuals and the number of fatal cancers to the regional population. The risk values for the M-1 unit are within a factor of three of the risk values for the reference boiler at the rural site which has similar emission rates. The risk estimates include estimates which use a dose rate effectiveness factor of 2.5, as described in Chapter 8, Volume I.

Table 4.1-14. Fatal cancer risks from radionuclide emissions from five utility boilers[a]

Source	Lifetime risk to nearby individuals		Regional population (Fatal cancers/y of operation)	
M-1	2E-5	(9E-6)	4E-3	(3E-3)
M-33	6E-6	(3E-6)	1E-3	(8E-4)
M-15	3E-7		1E-4	(9E-5)
M-34	1E-6	(5E-7)	1E-4	(9E-5)
M-99	7E-8	(4E-8)	1E-5	

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

4.1.8 Total Health Impact of Utility Boilers

An estimate of the potential health impact of utility boilers presently in operation may be made by assuming that the health effects due to emissions from the reference boiler are proportional to the health effects due to emissions from the whole industry.

About eight curies of uranium-238 per year are emitted by the whole industry. Most of the U.S. generating capacity from coal-fired utility boilers is located in areas that would be classified as either suburban or rural. Thus, the health impact from the industry may be estimated using this information and Table 4.1-11.

4.1.9 Existing Emission Standards and Air Pollution Controls

There are no radionuclide emission standards for utility boilers. However, particulate emission rates are regulated by EPA and the States. EPA administers New Source Performance Standards (NSPS) that apply to all utility boilers on which construction began after August 17, 1971, and before September 19, 1978, that have a firing capacity greater than 73 MW(t) or 25 MW(e). Under these standards, particulate emissions are limited to 43 ng/J. The 1979 revised New Source Performance Standards (RNSPS), which apply to all 73 MW(t) or 25 MW(e) electric utility steam generating units on which construction began after 19 September 1978, require that particulate emissions be limited to 13 ng/J (TRI81).

States regulate particulate emissions by State Implementation Plans (SIPs). These must ensure that emission limitations and reductions at new power plants are at least as stringent as those stipulated in the NSPS and RNSPS. The SIPs must also include emission limits for existing facilities (SIPs relate to National Ambient Air Quality Standards--NAAQS). All plants that were operating or under construction before August 17, 1978, must be assigned emission limits by the SIP to ensure attainment of air quality standards.

In most states, the SIP emission limits for pre-NSPS plants are considerably less stringent than the NSPS limits. A survey of current SIP limits shows that values of 43 and 86 ng/J are typical for the stringent and less stringent states, respectively. SIP-regulated power plants will continue to be the predominant source of electric utility emissions through the remainder of this century.

4.1.10 Supplemental Control Technology

Existing boilers can be retrofitted with additional electrostatic precipitators (ESPs) to reduce emissions to the level prescribed for new sources (13 ng/J); the number of fatal cancers is reduced also. EPA's Office of Air Quality Planning and Standards has listed the reduction in particulate emissions that would result from this action (RC83). Table 4.1-15 shows how these reductions can be related to population density. The reduction in uranium-238 emissions may be estimated by assuming a uranium-238 concentration of 9 pCi/g in fly ash emitted to the air. These reductions are listed in Table 4.1-16.

Cost of Reduced Impact

EPA's Office of Air Quality Planning and Standards has estimated the costs of retrofitting all existing coal-fired utility boilers with control devices to reduce particulate emissions (RC83). To reach a control level of 13 ng/J would result in a capital cost (1982 dollars) of about $13 billion and an annual cost of about $3.4 billion.

Table 4.1-15. Relationship of particulate emissions reduction to population density

Population density[a]	Generating capacity (MW)	Reduction in particulates to reach control level of 13 ng/J (10^4 tons/y)
0-50,000	8,070	2.5
50,000-100,000	7,040	2.1
100,000-250,000	7,140	2.2
250,000-500,000	43,820	13.3
500,000-1 million	82,840	25.3
1 million-2.5 million	72,700	22.2
2.5 million-5 million	31,080	9.5
5 million-10 million	15,430	4.7
Total	268,100	81.8

[a] Population within 80 km of a coal-fired utility boiler.

Source: (RC83).

Table 4.1-16. Reduction in uranium-238 emissions caused by reducing particulate emissions

Population density	Reduction in uranium-238[a] emissions (Ci/y)
0-50,000	0.2
50,000-100,000	0.2
100,000-250,000	0.2
250,000-500,000	1.2
500,000-1 million	2.3
1 million-2.5 million	2
2.5 million-5 million	0.9
5 million-10 million	0.4
Total	7

[a] These values are calculated by converting the reduction of particulates released in tons/year to grams/year, multiplying by the average concentration of uranium-238 in fly ash (9 pCi/g), and converting to curies (1 Ci = 10^{12} pCi).

REFERENCES

An77 Anson D., 1977, Availability of Fossil-Fired Steam Power Plants, Electric Power Research Institute, EPRI-FP-422 SR, Palo Alto, California, January 1977.

Be78 Beck H.L., et al., 1978, Perturbations of the National Radiation Environment Due to the Utilization of Coal as an Energy Source, Paper presented at the DOE/UT Symposium on the Natural Radiation Environment III, Houston, Texas, April 23-28, 1978.

Coa78 Coles D.G., Ragaini R.C., and Ondov J.M., Behavior of Natural Radionuclides in Western Coal-Fired Power Plants, Environmental Science & Technology, Volume 12, 14, April 1978.

Cob77 Considine D.M. (Editor-in-Chief), 1977, Energy Technology Handbook, McGraw-Hill Book Company, New York.

Coc75 Cowherd C., et al., 1975, Hazardous Emission Characterization of Utility Boilers, NTIS Report No. PB-245-915, July 1975.

Dea77 Dennis R., et al., 1977, Filtration Model for Coal Fly Ash with Glass Fabrics, EPA 600/7-77-084, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Deb79 Dennis R. and K.A. Klemm, 1979, Fabric Filter Model Format Change, Vol. 1, Detailed Technical Report, EPA 600/7-79-0432, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

DOE74 Department of Energy, 1974, Cost and Quality of Fuels for Electric Utility Plants, Energy Data Report, FPC Form 423, DOE/EIA-0075/9(79), September 1974.

DOE76 Department of Energy, Computer Tape Containing Federal Power Commission Form 67 Data for 1976, Energy Information Administration, Washington, D.C.

DOE77 Department of Energy, 1974, Cost and Quality of Fuels for Electric Utility Plants, Energy Data Report, FPC form 423, DOE/EIA-0075/9(79), September 1974.

DOE79 Department of Energy, 1979, Trends in the Capacity Utilization and Fuel Consumption of Electric Utility Power Plants, 1970-1978, Energy Information Administration, Washington, D.C.

REFERENCES (Continued)

EPA80 Environmental Protection Agency, Radiological Impact Caused by Emissions of Radionuclides into the Air in the United States, EPA 520/7-79-006, EPA, Office of Radiation Programs, Washington, D.C., 1980.

EPA81 Environmental Protection Agency, The Radiological Impact of Coal-fired Industrial Boilers, EPA, Office of Radiation Programs, Washington, D.C., (Draft Report), 1981.

IGS77 Illinois State Geological Survey, 1977, Trace Elements in Coal: Occurrence and Distribution, NTIS Report No. PB-270-922, June 1977.

RC83 Radian Corporation, Boiler Radionuclide Emissions Control: The Feasibility and Costs of Controlling Coal-fired Boiler Particulate Emissions, Prepared for the Environmental Protection Agency, January 1983.

Ro83 Roeck D.R., White M.O., Kiddie A.M., and Young C.W., Survey of Five Utility Boilers for Radionuclide Emissions, Prepared for EPA by GCA Corporation under Contract No. 68-02-3168, December 1983.

Sm80 Smith R.D., The Trace Element Chemistry of Coal during Combustion and the Emissions from Coal-Fired Plants, Progress in Energy and Combustion Science 6, 53-119, 1980.

St76 Stern A.C., Editor, 1976, Air Pollution, Vol. IV, Third Edition, Academic Press, Inc., New York.

TRI79a Teknekron Research, Inc., Utility Simulation Model Documentation, Vol. 1, R-001-EPA-79, Prepared for the Environmental Protection Agency, Washington, D.C., July 1979.

TRI79b Teknekron Research, Inc., Utility Simulation Model, Summary Resource and Residuals Report, Berkeley, California, 1979.

Wa82 Wagner P. and Greiner N. R., Third Annual Report, Radioactive Emissions from Coal Production and Utilization, October 1, 1980-September 30, 1981, LA-9359-PR, Los Alamos National Laboratory, Los Alamos, N. M., 1982.

4.2 Industrial Boilers

4.2.1 General Description

Coal-fired industrial boilers (CFIBs) are used mainly to produce process steam, generate electricity (for the producer's own use), and provide space heat. The boilers are used in virtually every industry from small manufacturing plants to large production concerns. The major users are the steel, aluminum, chemical, and paper industries. Of the coal consumed by industrial boilers in 1974, more than 87 percent was used by these four industries alone. A breakdown of the percent of total coal consumed by each industry is given in Table 4.2-1.

Table 4.2-1. Industrial coal consumption, 1974

Industry	Coal consumption (Percent of total)
Chemicals	33
Paper	26
Steel and aluminum	28
Food	10
Other manufacturing	3

Source: (EPA80).

4.2.2 Process Description

Types of Boilers

Three basic types of boilers are used in the industrial sector: (1) water tube, (2) fire tube, and (3) cast iron.

Water tube boilers are designed so that water passes through the inside of tubes that are heated externally by direct contact with hot combustion gases. The process produces high pressure, high temperature steam with a thermal efficiency of about 80 percent. Water tube boilers range in capacity from less than 3 MW to over 200 MW thermal input.

Fire tube boilers are designed to allow the hot combustion gas to flow through the tubes. Water to be heated is circulated outside the tubes. The boilers are usually smaller than 9 MW thermal input.

Cast iron boilers are designed like fire tube boilers with heat transfer from hot gas inside the tubes to circulating water outside the tubes, but cast iron is used rather than steel. Cast iron boilers are generally designed for capacities less than 3 MW.

Number and Capacity of Boilers

Table 4.2-2 lists the number of boilers and their total installed capacity (EPA81). Water tube units represent 89 percent of the total installed capacity of all boilers in terms of the thermal input. Since the capacity (amount of coal burned) influences the level of emissions to the environment, the radiological impact of coal-fired industrial boilers will be that associated with emissions from water tube type units. Cast iron and fire tube units will not be considered further in this report.

Table 4.2-2. Number and capacity of coal-fired industrial boilers

Boiler type	Unit capacity (MW thermal input)				
	0-3	3-15	15-30	30-75	75 plus
Water Tube Units	683	2309	1290	1181	423
Total MW	835	22225	27895	50825	59930
Fire Tube Units	8112	1224			
Total MW	5650	7780			
Cast Iron Units	35965				
Total MW	6330				

Coal-Firing Mechanisms

There are two main types of coal-fired water tube boilers: pulverized coal and stoker-fired. Pulverized coal units burn coal while it is suspended in air. Units range in size from 30 MW to over 200 MW heat input. A stoker unit has a conveying system that serves to feed the coal into the furnace and to provide a grate upon which the coal is burned. Stokers are generally rated at less than 120 MW heat input. The three main types of stoker furnaces are spreader, overfeed (or chain grate), and underfeed. Each of the boiler types is discussed below.

Pulverized coal-fired boilers

Coal is pulverized to a light powder and pneumatically injected through burners into the furnace. If the furnace is designed to operate at a high temperature (typically 1600° C), the ash remains in a molten state until it collects in a hopper at the bottom of the furnace. The high temperature units are known as "wet bottom" units.

"Dry bottom" units operate at lower combustion temperatures with the bottom ash remaining in the solid state. Combustion temperatures initially reach about 1200-1600° C.

Spreader stoker

Coal is suspended and burned as a thin, fast-burning layer on a grate, which may be stationary or moving. Feeder units are used to spread the coal over the grate area, and air is supplied over and under the grate to promote good combustion.

Overfeed stokers

Coal is fed down from a hopper onto a moving grate that enters the furnace. Combustion is finished by the time the coal reaches the far end of the furnace, and ash is discharged to a pit.

Underfeed stokers

Coal may be fed horizontally or by gravity, and the ash may be discharged from the ends or sides. Usually the coal is fed intermittently to the fuel bed with a ram, the coal moving in what is in effect a retort, and air is supplied through openings in the side grates.

Particulate Emissions by Boiler Type

The fractional distribution of ash between the bottom ash and fly ash directly affects the particulate emissions rate and is a function of the following parameters:

> Boiler firing method. The type of firing is the most important factor in determining ash distribution. Stoker-fired units emit less fly ash than pulverized coal-fired boilers.
>
> Wet or dry bottom furnaces. Dry bottom units produce more fly ash.
>
> Boiler load. Particulate emissions are directly proportional to the amount (load) of coal burned.

4.2.3 Control Technology

Radionuclides are removed from flue gas with the particulates. The following paragraphs discuss technologies commonly used to remove particulates.

Electrostatic Precipitators

Particle collection in an electrostatic precipitator (ESP) occurs in three steps: (1) suspended particles are given an electric charge,

(2) the charged particles migrate to a collecting electrode of opposite polarity where they are collected, and (3) the collected particulates are dislodged from collecting electrodes. Energy is needed to operate the precipitator in amounts equivalent to 0.02 to 0.1 percent of the fuel energy input to the boiler. ESP efficiency varies with a number of factors, of which particle size is most significant. Table 4.2-3 shows typical efficiencies.

Table 4.2-3. ESP collection efficiency as a function of particle size

Particle diameter (micrometer)	Average collection efficiency (percent)
0-5	72
5-10	94.5
10-20	97
20-44	99.5
Greater than 44	100

Fabric Filter

In fabric filtration, particle-laden flue gas is passed through the fabric to trap particles; the cleaned gas passes through the fabric into the atmosphere.

Energy is required to operate equipment, such as fans, cleaning equipment, and the ash conveying system. The energy requirement depends on the type of boiler and its capacity; it ranges from 3 to 8 times as great as the energy required for an ESP.

The overall mass collection efficiency of a fabric filter ranges from 99 to 99.9 percent with an average of roughly 99.7 percent. Fabric filter control efficiency is not affected by changes in coal sulfur and alkali content, variables which can signicantly affect ESP performance. The efficiency of the fabric filter is also not sensitive to the inlet particle size distribution.

Wet Scrubber

Scrubbers operate on the principle of capturing particulates by bringing them into contact with liquid droplets or wet scrubber walls. They require significant amounts of energy to operate fans and liquid pumps. The energy requirements, which range from 0.2 to 0.7 percent of the fuel energy input to the boiler, depend on the type of boiler and its capacity, characteristics of coal consumed, and level of particulate matter control.

The control efficiency of wet scrubbers is a function of system pressure drop and inlet particle size distribution. Typical collection efficiencies, as a function of pressure drop, are shown in the Table 4.2-4.

Table 4.2-4. Typical wet scrubber efficiency

Pressure drop (KPa)	Overall collection efficiency (percent)
1.24	88-95
2.5	92-97
5.0	95-98
7.5	96-99

Mechanical Collectors

The typical mechanical collector is the cyclone collector. The cyclone collector transforms the velocity of an inlet gas stream into a confined vortex from which centrifugal forces tend to drive the suspended particles to the wall of the cyclone body.

The energy requirements are roughly 1 to 2 1/2 times greater than that of ESPs or about 0.12 percent of the fuel energy input to the boiler.

The level of efficiency of the mechanical collector (cyclone) is much lower than ESPs, fabric filters, or wet scrubbers. Additionally, the mechanical collector becomes less efficient as particle size decreases. Accordingly, they are not used to remove small particles.

4.2.4 Radionuclide Emissions

Radionuclide emission rates from coal-fired industrial boilers have not been measured. However, by knowing the radionuclide concentrations in either fly ash or coal, radionuclide emissions from boilers can be estimated.

Table 4.2-5 lists additional estimates of uranium-238 emission rates from representative coal-fired industrial boilers. The estimates of particulate emissions reflect the range of emissions that characterize the entire population of industrial boilers, and the uranium-238 emissions are calculated using average values for coal and boiler characteristics (e.g., heat value, capacity factors) that influence emission rates (TRI81).

Table 4.2-5. Estimated uranium-238 emission rates for representative coal-fired industrial boilers

Boiler capacity (MW)	Emission control	Particulate matter (ng/J)	Uranium-238 emissions (Ci/y)
9	yes	194	1E-4
	no	782	4E-4
22	yes	172	3E-4
	no	712	1E-3
44	yes	138	4E-4
	no	1850	6E-3
59	yes	129	7E-4
	no	2420	7E-3
118	yes	86	9E-4
	yes	43	4E-4

We estimate the uranium-238 emission rate for the entire population of large (15 MW and greater) coal-fired industrial boilers subject to SIP particulate matter limits to be 3 Ci/y.

4.2.5 Reference Coal-Fired Boiler

We chose the source term of the reference case (see Table 4.2-6) industrial boiler to resemble the amount of radionuclides that could be released from a large industrial boiler to air under normal operations. Our source term assumptions were conservative so that our projected radiological impacts should be greater than most, but possibly not all, new and existing industrial boilers. There could be different combinations of plant size, coal radionuclide content, levels of control technology, etc., that would yield a source term approximately equal to the one we selected for the reference case.

The source term was calculated using the same methodology used for utility boilers (see Section 4.1) and reflects the relatively smaller thermal capacity and coal consumption of industrial boilers. Table 4.2-7 lists other characteristics of the reference boiler used in the health impact assessment.

Table 4.2-6. Radionuclide emissions from the reference boiler

Radionuclide	Emissions (Ci/y)
Uranium series:	
Uranium-238	1.0E-2
Uranium-234	1.0E-2
Thorium-230	5.0E-3
Radium-226	7.5E-3
Radon-222	2.5E-1
Lead-210	2.5E-2
Po-212	2.5E-2
Thorium series:	
Thorium-232	4.3E-3
Radium-228	6.5E-3
Actinium-228	4.3E-3
Thorium-228	4.3E-3
Radium-224	6.5E-3
Radon-220	8.3E-2
Lead-212	2.2E-2
Bismuth-212	4.3E-3
Thallium-208	4.3E-3

Table 4.2-7. Reference coal-fired industrial boiler

Parameter	Value
Site	Midwest location (St. Louis)
Population	2.5 million people within 80 km of the site
Stack	
Effective height	150 meters
Diameter	1.5 meters

4.2.6 Health Impact Assessment of Reference Industrial Boiler

The estimated annual radiation doses from the reference industrial boiler are listed in Table 4.2-8. Table 4.2-9 presents estimates of the lifetime risk of fatal cancer from these doses.

4.2.7 Total Health Impact of Coal-Fired Industrial Boilers

The total number of fatal cancers caused by all coal-fired industrial boilers may be estimated by multiplying the health effects for the reference boiler by the ratio of the total (estimated) uranium-238 emissions of the entire CFIB industry and the reference boiler.

Table 4.2-8. Radiation dose rates from radionuclide emissions from the reference industrial boiler

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Lung	3.4E-1	7.6E+1
Red marrow	4.0E-2	6.6
Kidney	4.0E-2	9.0
Bone	4.3E-1	9.0E+1
Liver	2.0E-2	3.2

Table 4.2-9. Fatal cancer risks due to radionuclide emissions from the reference industrial boiler[a]

Source	Lifetime risk to nearby individuals	Regional population (Fatal cancers/y of operation)
Industrial boiler	6E-7 (5E-7)	3E-3

---

[a] The risk estimates in parentheses include a dose rate reduction factor of 2.5 for low-LET radiations, as described in Chapter 8, Volume I, of this report.

4.2.8 Existing Emission Standards and Air Pollution Control

No Federal or state regulations currently exist that limit emissions of radionuclides from coal-fired industrial boilers. However, the states, through State Implementation Plans (SIPs), and the Federal government, through New Source Performance Standards (NSPS), regulate particulate matter emissions and thus effectively limit radionuclide emissions.

All existing coal-fired industrial boilers are subject to SIPs. Since the individual SIPs reflect local conditions and needs, particulate matter emissions vary from state to state.

All new coal-fired industrial boilers with capacities greater than 73.3 MW (thermal input) are subject to a particulate emission limit of 43.3 ng/J (40 CFR 60, subpart D.) New boilers with capacities less than 73 MW are subject to limits prescribed by the SIPs.

4.2.9 Supplemental Control Technology

Currently, large coal-fired industrial boilers (15 MW and greater), which are subject to SIP particulate matter limits, emit about 0.37 million tons of particulate matter per year. Table 4.2-10 lists the costs, particulate matter emission levels, and cost-effectiveness to retrofit large boilers to meet specific uniform emission levels (RC83).

Table 4.2-11 lists estimated uranium-238 emissions for existing and retrofitted large boilers (15 MW and larger) subject to SIP particulate matter control.

Table 4.2-12 lists estimated current risks and risk reductions for particulate matter limits for large (15 MW and greater) coal-fired industrial boilers.

Table 4.2-10. Estimated costs and particulate matter reductions from retrofit controls for coal-fired boilers[a]

Costs	Emission level	
	(0.1 lbs/10^6BTU)	(0.05 lbs/10^6BTU)
Capital Cost	\$2.5 billion	\$3.4 billion
Annual Cost	\$550 million	\$730 million
Particulate matter reduction	0.15 million tons/y	0.19 million tons/y
Cost effectiveness: (\$/ton)	\$3,600	\$3,800

[a] 15 MW and greater boilers.

Table 4.2-11. Estimated uranium-238 emission rates for existing and retrofitted large coal-fired industrial boilers[a]

Particulate matter control level rate (lbs/10^6 BTU)	Uranium-238 emission rate (Ci/y)
Various under SIPs	2.9
0.1	1.7
0.05	1.4

[a] 15 MW and greater.

Table 4.2-12. Risks associated with large coal-fired industrial boilers[a]

Particulate matter control level	Risk reduction factor
Various under SIPs	1
0.1	0.3
0.05	0.4

[a] 15 MW and greater.

REFERENCES

EPA80	Environmental Protection Agency, 1980, Fossil Fuel-Fired Industrial Boilers--Background Information for Proposed Standards, Chapters 3-5, Research Triangle Park, N.C.
EPA81	Environmental Protection Agency, The Radiological Impact of Coal-Fired Industrial Boilers (Draft), EPA Office of Radiation Programs, Washington, D.C., October 1981.
TRI81	Teknekron Research, Inc., Draft Background Information Document for Coal-Fired Industrial Boilers, Unpublished, May 1981. (Available in EPA Docket A-79-11.)
RC83	Radian Corporation, Boiler Radionuclide Emissions Control: The Feasibility and Costs of Controlling Coal-Fired Boiler Particulate Emissions, Prepared for EPA, January 1983.

Chapter 5: URANIUM MINES

5.1 General Description

In uranium mining operations, ore is removed from the ground in concentrations of 0.1 to 0.2 percent U_3O_8 or 280 to 560 microcuries of uranium-238 per metric ton of ore. Since the uranium-238 in the ore is normally present in secular equilibrium with its daughter products, these ores also contain equal amounts of each member of the uranium-238 decay series.

After mining, the ores are shipped to a uranium mill to separate the uranium. Radioactive emissions to air from uranium mines and mills consist of radionuclide bearing dust and radon-222 gas.

Uranium is mined in both open pit and underground mines. In 1982 there were 139 underground and 24 open pit uranium mines in operation in the United States (Table 5-1). These mines accounted for about 75 percent of the uranium produced (DOE83).

Table 5-1. Distribution of 1982 U_3O_8 production by mining method (DOE83)

Source	Number	Tons U_3O_8[a]	Percent of total
Underground mines	139	6,200	46
Open pit mines	24	3,900	29
Solution Mining (In-Situ)	18	1,500	11
Others: heap-leach, mine water, byproduct, and low-grade stockpiles	15	1,800	14
Total	196	13,400	100

(a)Short tons

In recent years in-situ solution mining has been more widely used; this method is expected to increase in future years. During 1982 this method accounted for 11 percent of the uranium mined in the United States. The radioactive emissions from this source are small compared to the other sources.

Table 5-2 indicates that at present all uranium is mined in the western United States, mostly in the states of New Mexico, Wyoming, and Texas. Exploration for uranium is being conducted, however, in the eastern and midwestern parts of the United States.

Table 5-2. Distribution of 1982 U_3O_8 production by State (DOE83)

State	U_3O_8 (Short tons)	Percent of total
New Mexico	3,800	28
Wyoming	2,700	20
Texas	2,200	17
Arizona, Colorado, Florida, Idaho, Utah, & Washington	4,700	35
Total	13,400	100

Major publicly-held corporations account for a large share of ownership in the uranium industry. The industry grew rapidly in the early and mid-1970's, stimulated by expectations of rapid increases in demand. However, the expectations were too optimistic, with supply outstripping demand. The result was an economic slump for the industry. The industry is now faced with excess capacity, large inventories, lower-than-expected demand, and the potential for increased competition from imports (EPA83a).

5.2 Process Description

Underground Mining

Underground uranium mining is usually carried out using a modified room and pillar method. In this method, a large diameter main entry shaft is drilled to a level below the ore body. A haulage way is then established underneath the ore body. Vertical raises are driven up from the haulage way to the ore body. Development drifts are driven along the base of the ore body connecting with the vertical raises. Mined ore is hauled along the development drifts to the vertical raises and gravity fed to the haulage way for transport to the main shaft for hoisting to the surface.

Figure 5-1 is an example of an underground mining operation. Ventilation shafts are installed at appropriate distances along the ore body. Typical ventilation flow rates are on the order of 200,000 cfm. The principal radioactive effluent in the mine ventilation air is radon-222 which is released during mining operations. Additional radon-222 and particulate (uranium and its decay products) emissions result from surface operations at the underground mine.

Surface Mining

Open pit mining usually is carried out by excavating a series of pits in sequence. The topsoil and overburden are removed from above the ore zone and stockpiled in separate piles for use in future reclamation operations. The uranium ore is removed from the exposed ore zone and stockpiled for transport to a uranium mill. Ore stockpiles range in size up to several hundred thousand metric tons of ore. During the mining of the uranium ore, low grade waste rock is also removed from the pits and stored in a waste stockpile for possible future use.

Figure 5-2 is an example of an open pit mining operation. As the mining progresses, mining and reclamation operations take place simultaneously--pits are mined in sequence, and the mined-out pits are reclaimed by backfilling with overburden and topsoil. In some cases, the last of the open pits in a mining operation are not backfilled but are allowed to fill with water, forming a lake. Radioactive emissions from open pit mining operations are radon-222 gas and fugitive dust containing uranium and its decay products.

In-Situ Mining

In this method, a leaching solution is injected through wells into the uranium-bearing ore body to dissolve the uranium. Production wells bring the uranium-bearing solution to the surface where the uranium is extracted. The solution (lixiviant) can be recovered and reused.

Radon-222 gas is emitted from the processing operations and waste impoundments. With solution mining, less than 5 percent of the radium from an ore body is brought to the surface (NRC80). Consequently, the amount of radon released is considerably less than that from conventional mining. The major sources of radon are the surge ponds, enclosed surge tanks, inplant surge tanks, and absorption columns (Br81). It is estimated that the radon released is about 19 percent of the amount released from a conventional uranium mill (Bra81).

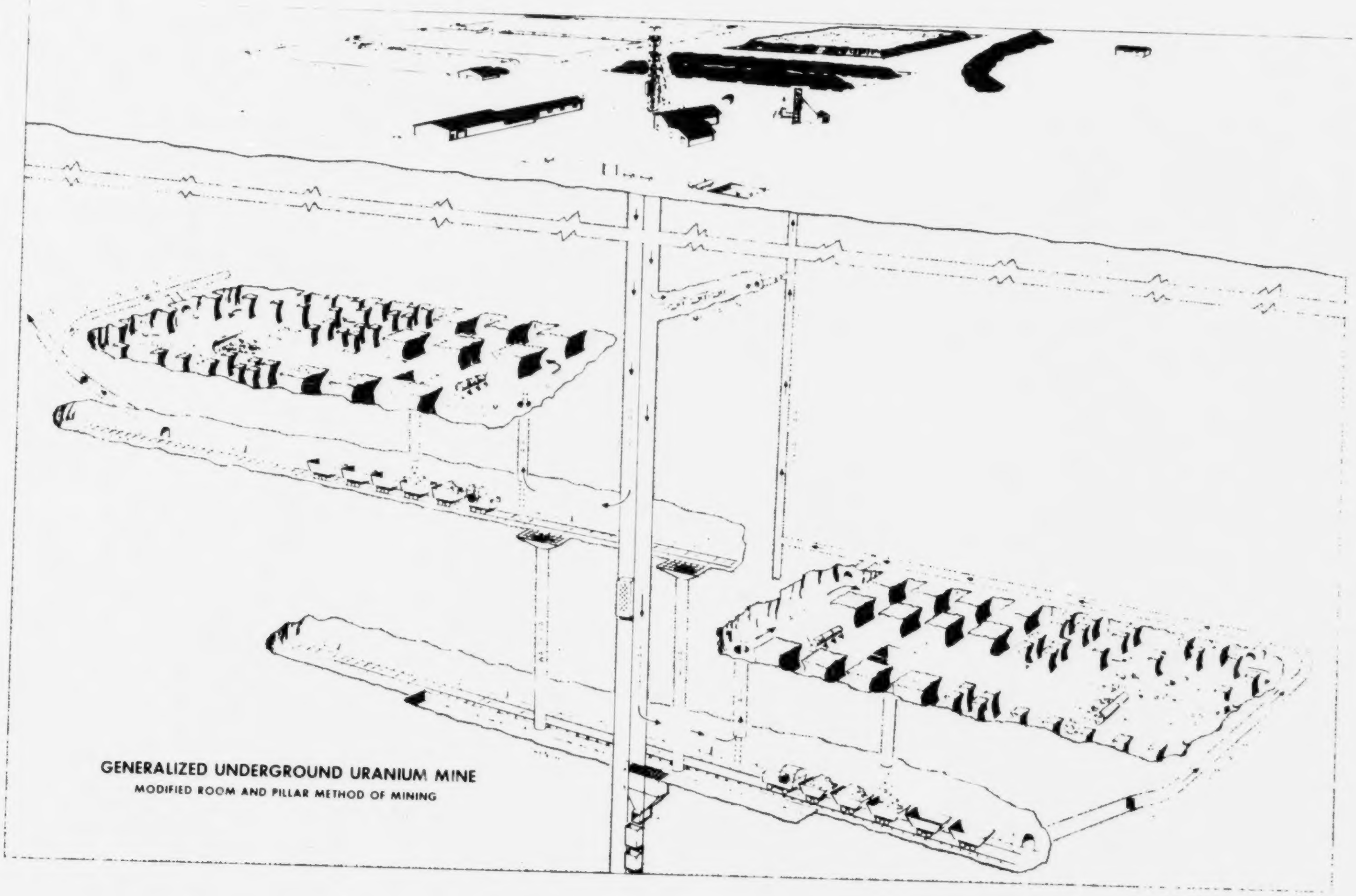

GENERALIZED UNDERGROUND URANIUM MINE
MODIFIED ROOM AND PILLAR METHOD OF MINING

Figure 5-1. An underground uranium mining operation.

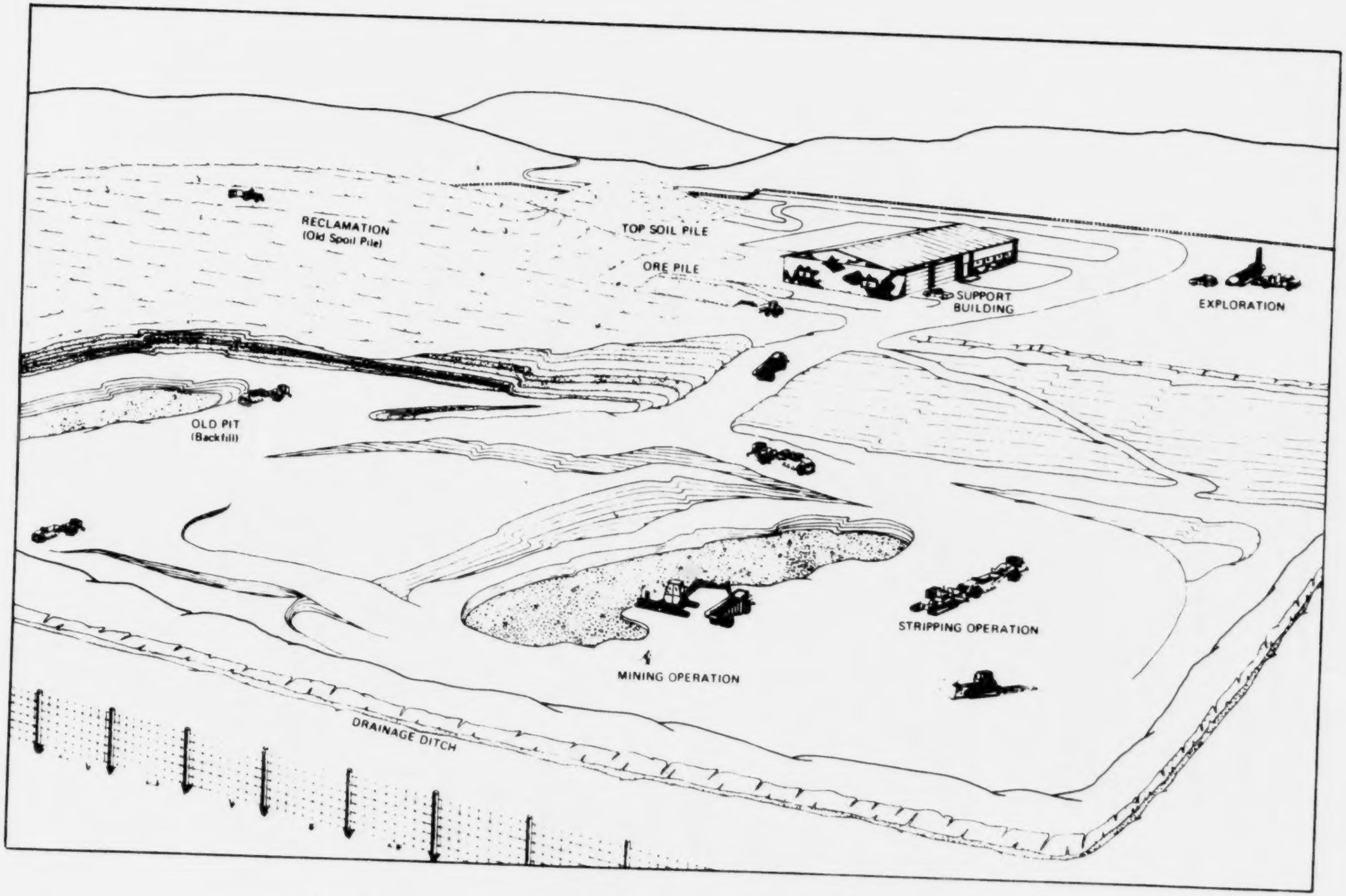

RECLAMATION
(Old Spoil Pile)
TOP SOIL PILE
ORE PILE
SUPPORT BUILDING
EXPLORATION
OLD PIT
(Backfill)
STRIPPING OPERATION
MINING OPERATION
DRAINAGE DITCH

Figure 5-2. An open pit uranium mining operation.

A small amount of radon is released from the waste impoundments used to store contaminated liquids from the operation. Some examples of solid wastes (EPA83b) that might be generated by the alkaline leach in-situ process are:

(1) Materials filtered from the lixiviant line,
(2) Sediments from the surge tanks,
(3) Calcium carbonate from the calcium control unit,
(4) Barium sulfate from the cleanup of the elution/precipitation circuit of the recovery process,
(5) Materials deposited in the evaporation ponds,
(6) Drill hole residues,
(7) Solids from aquifer restoration.

EPA has previously evaluated radionuclide emissions from uranium mining activities (EPA79, EPA83b). These evaluations indicate that underground uranium mining releases the largest quantities of radon-222 to air and results in the most significant health impacts when compared to other mining methods. Because of the lower amounts of radon released from surface mines, in-situ solution mining, and other mining methods, the potential health impact of underground uranium mining is of the most concern and therefore, Sections 5.3 through 5.8 of this chapter deal only with underground uranium mines.

5.3 Control Technology

Several methods to control radon emissions from underground uranium mines have been evaluated. These are: 1) use of sealant coating on exposed ore surfaces; 2) bulkheading of worked-out areas; 3) activated carbon adsorption of radon from contaminated mine air; 4) mine pressurization; and 5) miscellaneous technologies.

Sealant Coating

One method for controlling radon in an underground uranium mine is to prevent radon from entering the mine air by sealing exposed surfaces. A summary of field tests and a review of the literature on this subject performed for EPA (Ko80) is summarized as follows:

1) Under laboratory conditions sealants are very effective in attenuating radon emissions from ore surfaces, but in an actual mine application, the presence of "pinholes" and the difficulty of applying a perfect coating on a mine wall or ceiling surface reduces the effectiveness of these sealants considerably.

2) In field tests a three-coat system of HydroEpoxy 156 and HydroEpoxy 300, preceded by Shotcrete base coating, was found to be effective (50 to 75 percent radon stoppage). For the theoretical mine, the sealant probably would be 60 percent effective with an eight-month lifetime.

3) The amount of sealants used varied considerably for different mines. Kown and his associates (Ko80) chose the following amounts for their study which were greater than other studies on this subject.

Shotcrete - 909 gal per 1000 ft^2
HydroEpoxy 156 - 18 gal per 1000 ft^2
HydroEpoxy 300 - 32 gal per 1000 ft^2

4) The sealant coating applied to drifts of an underground mine has a limited life of about eight months because the drift area is mined after pillars are extracted in a room-and-pillar stope mine.

5) An asphalt emulsion sealant has been tested in the laboratory and on tailing piles and is found to be an effective, inexpensive sealant. However, it has not yet been tested in an underground mine atmosphere.

The cost of coating 530,000 ft^2 of drift surfaces in the mine was $348,100 ($1.45 per ton of ore removed). The floors were not considered to be coated because ore loaders will destroy the coating on the semiconsolidated muck. The three sealants were applied every two months. Cost estimates of other sealants range from $0.30 to $1.10 per square foot (Fr81) which is comparable to the cost estimates ($0.66 per square foot) of the sealants used in this study. Because of its high cost, the Bureau of Mines feels that sealants may only be used economically in shops, lunchrooms, and possibly high-emanating areas in intake airways (Frc83).

A recent study by Battelle (B184) of 13 mines shows an average cost of $5.80 per ton of ore mined ($0.34 per square foot) if 80 percent of the surface is sealed. This EPA-sponsored study has shown that sealants could reduce the radon emanation from the active stopes of the mines by 23 percent. If the total mine is included (25 extracted stopes), only 11 percent of the radon was reduced. This second figure should be used when determining the amount of radon released from the mine.

Other studies by the Bureau of Mines (Fra81) have shown that 50 to 75 percent of the radon can be retained in the rock by sealants. The study by Battelle (B184) shows that a 56 percent reduction in radon emissions can be achieved by applying sealant to 80 percent of the mine surfaces.

Bulkheading

Bulkheading of mined-out areas, such as extracted stopes, is the most common radon control method currently practiced in underground mines (Ko80). In general, it is used to isolate worked-out areas or stopes from workers so that the radon concentrations in the working areas of the mine will be lower. If the bulkhead is air tight, the radon behind the barrier will decay to innocuous levels. However, all bulkheads leak to some extent, and usually a small 3- to 6-inch ventilation pipe is used as a bleeder pipe to provide negative pressure in the extracted stope (Fra81) and to allow the contaminated air to be diverted to the ventilation system. A small fan may be required to maintain the negative pressure. Ideally, only 10 percent of the air behind the bulkhead would be diverted to the outside atmosphere. This air stream can also be connected to an activated carbon filter or trap to reduce concentrations further.

In an EPA study (Ko80) it was assumed that 12.5 stopes per year would be sealed using 100 bulkheads. The cost for material, labor, and maintenance was estimated to be $80,400 or $0.34 per ton of ore removed. It was also assumed that a six-inch pipe provided a 100 cfm bleeding rate from each bulkheaded area. In a Battelle study (B184) the average cost to bulkhead 80 percent of the mine at 13 sites was only $0.08 per ton of ore. Up to 10 bulkheads in each mine were used in making these estimates.

An estimate of the effectiveness of reducing radon by this system was made using many crude assumptions. For the total mine, bulkheading was estimated to achieve about a 14 percent reduction in radon emissions (Ko80). A preliminary study conducted by Battelle on an actual mine indicated that a radon reduction of 35 percent could be obtained by using bulkheads (Dra80, Th81). Using bulkheads extensively in a mine can reduce radon emissions up to 60 percent (B184).

Radon Adsorption on Activated Carbon

Leakage of high radon concentrations through bulkheads used to control radon concentrations in mines is another problem. One method to relieve this problem is to insert a small bleeder pipe in the bulkhead to provide negative pressure within the enclosed area behind the bulkhead. This bleeder pipe is usually connected to the exhaust ventilation system. Although this may prevent exposure to the workers, the radon emissions to the environment may still be high. An activated carbon adsorption system may be attached to the radon effluent pipe before releasing this air to the exhaust ventilation system (Ko80).

An effective radon control system for the bleeder pipes is still under study. The system chosen by investigators in an EPA study (Ko80) is shown in Figure 5-3. It consists of two carbon adsorption systems in series. The flow from the bleeder pipe is filtered to remove dust particles and radon daughter products. The radon is then adsorbed in the carbon column. The carbon column is regenerated once a day, using hot air. The contaminated air from the regeneration is sent through a second carbon column to again adsorb the radon gas. Occasional drying may be required in the second column due to buildup of moisture.

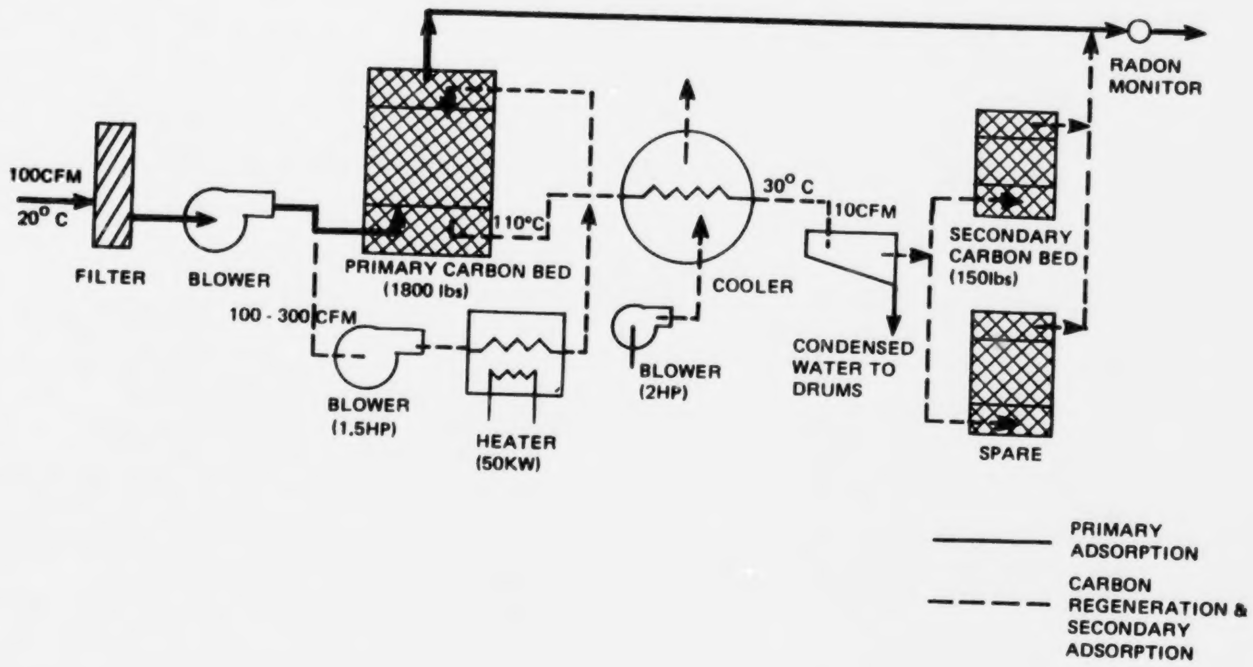

100CFM
20° C
FILTER
BLOWER
PRIMARY CARBON BED
(1800 lbs)
110°C
100 - 300 CFM
BLOWER
(1.5HP)
HEATER
(50KW)
30° C
COOLER
BLOWER
(2HP)
10CFM
CONDENSED
WATER TO
DRUMS
SECONDARY
CARBON BED
(150lbs)
SPARE
RADON
MONITOR
PRIMARY
ADSORPTION
CARBON
REGENERATION &
SECONDARY
ADSORPTION

Figure 5-3. Radon removal from mine air by carbon adsorption.

In evaluating control technology in a model mine, EPA (Ko80) found that an average of 12.5 activated carbon systems must be installed each year to treat the contaminated air from the stopes sealed by the bulkheads. The capital and operating costs for each unit are as follows:

Capital Cost of Each Unit

Major equipment	$22,000
Auxiliaries & Installation	$11,000
Total	$33,000

Annualized Cost of Each Unit

Material (carbon, filters, piping)	$ 1,000
Utilities (25,000 kwh @ 4¢/kwh)	$ 1,000
Labor (0.25 person-year)	$ 8,000
Amortizing (an avg. 5-year life at 10 percent interest)	$ 8,700
Total	$18,700

Assuming the lifetime of each unit is 5 years and 12.5 units per year are needed, the cost over five years would be $1,037,500 or $0.86 per ton of ore mined. The carbon system was assumed to be 95 percent efficient in removing radon.

The effectiveness of the entire system, including bulkheading and carbon traps, was estimated to be 49 percent. A study by Battelle (Dra80) estimates a 45-68 percent effectiveness, using absolute sorption traps in combination with bulkheading. The total cost for bulkheading and carbon traps would be $1.20 per ton of ore mined for 100 bulkheads. In the study by Battelle (B184) the average cost to bulkhead with a carbon trap at 13 mines was $0.11 per ton of ore with an efficiency of 80 percent. Up to 10 bulkheads in each mine were used for their estimate.

There are some definite disadvantages to the carbon adsorption system. Skilled operators, usually not available in mining communities, are necessary to operate and maintain the system. Safety problems to the miners are possible due to interrupted electrical service or system malfunction. Excess radon concentrations would then be present. The carbon columns would have to be shielded to prevent gamma exposure to the miners. The system may not work in wet mines because of moisture absorption by the carbon.

The system does appear to be technically feasible utilizing commercial carbons and standard equipment. However, additional developmental work may be necessary before such a system can be used in a mine environment. A recent study by Hopke (Ho84) has concluded that activated carbon can be used for effective cleaning of small volumes of air such as effluents from a bleeder pipe for a bulkhead.

Mine Pressurization

Positive mine pressurization has been tried several times to force the radon in the mine atmosphere back into the walls of the mine (Ko80 and Fra81). In general, these efforts have been successful in reducing the radon concentrations in the mine itself. An "air" sink is necessary to accept the radon. If the radon is forced through the ore body or surrounding area to the surface, the radon can decay before coming to the surface. If the area is impermeable, however, radon levels will return to previous levels. In tests by the Bureau of Mines (Fra81), the radon levels in the mine were reduced by 20 percent (releases to the atmosphere were not determined). The surrounding soil needs to be permeable enough to hold radon and allow for its decay, but not so permeable so as to allow significant increases in surface emissions (Ko80). The costs of mine pressurization were not available because the process was in a development stage. In a recent report, Battelle (Bl84) concluded that positive pressure ventilation has been proven ineffective in reducing atmospheric emissions of radon.

Miscellaneous Radon Control Technology

Argonne National Laboratory is experimenting with strong oxidizing agents, such as bromine triflouride and dioxygenyl hexaflouro-antimonate, to convert the radon to another form that can be absorbed on a scrubber or absorption bed (Fra81). However, the corrosive and toxic nature of the reactants makes their use in mines impracticable and questionable. Battelle (Bl84) mentions other methods such as cryogenic methods, chemical removal, and gas centrifuge, but the costs are prohibitive. The study by Hopke (Ho84) reviewed methods for the removal of radon from uranium mine effluents. Methods, including cryogenic condensation, molecular sieves, gas centifugation, semipermeable membranes, and hybrid systems, do not offer much promise for a practical removal system. They do suggest the exploration of the class of perfluorinated hydrocarbon compounds as possible candidate scrubbing fluids for a radon scrubbing system.

Backfilling of worked-out areas with classified mill tailings is practiced by mine operators to provide ground support in the mine (Fr81). This procedure can also reduce ventilation requirements. A study, by the Bureau of Mines and Kerr-McGee Nuclear, to determine the effectiveness of reducing radon emissions by backfilling mill tailings into the mine stopes indicated a net radon reduction of 84 percent from the stope (Frb81). This was done for only one stope in a mine. PNL (Bl84) estimated an efficiency up to 80 percent if classified mill tailings and surface sands are used for backfilling with an average cost of $12.64 per ton of ore mined.

Increasing the height of vents is a possible method to reduce ground level radon concentrations in ambient air (Dra80). One of the conclusions based on a theoretical model was that "a 20-meter release height reduces the annual average concentration (when compared to a ground-level release) by about 60 percent at one mile from a source and by about 30 percent at ten miles from the source." An estimate of cost is $0.493 - $0.881/ton of ore for a 20-meter stack (Brb84). The average number of vents for a mine is about 5 (Ja80). Thus, the cost per mine would be about $3.44 per ton of ore produced.

Vent orientation is an important factor in radon concentrations near a mine (Drc84). Because of plume rise, concentrations are much lower when vents are in a vertical configuration (rather than horizontal), resulting in a reduction factor of 80 at sites near a mine with a vertical vent configuration.

Summary of Costs and Efficiencies

A summary of the costs and efficiencies of the various radon control technologies discussed previously is shown in Table 5-3.

Table 5-3. Cost and efficiencies of radon control technologies for underground uranium mines

Method	Radon reduction (Percent)	Cost ($/ton of ore)
Sealant coating	11 - 56	1.45 - 5.80
Bulkheading	14 - 60	0.08 - 0.34
Bulkheading with activated carbon	49 - 80	0.11 - 1.20
Mine pressurization	20	-
Stacks	60[a]	3.44
Backfilling	80 - 84	12.64

[a] Reduction in exposure to nearby individuals.

5.4 Radionuclide Emission Measurements

Radon-222 is the radionuclide emitted from underground uranium mines which causes the greatest risk to people. The major source of radon-222 emissions to air are the mine vents through which the ventilation air is exhausted. A large underground mine will usually have several vents; some mines have as many as 14 vents. Radon-222 emissions from these vents are highly variable and depend upon many interrelated factors including: ventilation rate, ore grade, production rate, age of mine, size of active working areas, mining practices, and several other variables.

Pacific Northwest Laboratories (PNL) has measured the radon-222 emissions from 27 underground uranium mines (Table 5-4) (Ja80). The average radon-222 emission rate for these 27 mines was 5,600

Table 5-4. Measurements of radon-222 emissions from underground uranium mine vents (Ja80)

Mine	Number of vents	Measurements (Ci/y)		
		1979	1978	Average
A	4	7,400	-	7,400
B	6	4,700	4,300	4,500
C	4	5,200	3,900	4,600
D	2	3,600	-	3,600
E	14	29,800	-	29,800
F	13	9,200	9,500	9,400
G	5	2,200	1,500	1,800
H	10	15,200	-	15,200
I	11	1,700	-	1,700
J	9	7,800	8,100	7,900
K	4	7,000	5,900	6,400
L	8	1,500	1,300	1,400
R	8	15,000	14,600	14,800
T	5	1,900	-	1,900
U	3	900	-	900
V	2	1,000	-	1,000
Y	7	17,500	-	17,500
Z	3	-	2,600	2,600
AA	2	2,100	1,500	1,800
BB	5	2,100	1,800	2,000
CC	3	-	2,100	2,100
DD	2	-	1,000	1,000
EE	5	6,500	-	6,500
FF	3	2,500	-	2,500
GG	3	200	100	200
HH	2	1,000	-	1,000
II	2	500	-	500
Average	5	6,100	4,200	5,600

curies/year. The emissions from individual vents ranged from 2 to 9,000 Ci/year with an average of 1,000 Ci/year.

In addition to the mine vents, radon-222 is emitted to air from several above-ground sources at an underground uranium mining operation. These sources are the ore, subore, and waste rock storage piles. PNL has estimated the radon-222 emissions from these sources to be about 2 to 3 percent of the emissions from the vents (Ja80). EPA has estimated the emissions from the above-ground sources to be about 10 percent of mine vent emissions (Table 5-5).

Table 5-5. Estimated annual radon-222 emissions from underground uranium mining sources (EPA83b)

Source	Average large mine[(a)] (Ci/y)
Underground	
Mine vent air	3,400
Aboveground	
Ore loading and dumping	15
Sub-ore loading and dumping	5
Waste rock loading and dumping	0
Reloading ore from stockpile	15
Ore stockpile exhalation	53
Sub-ore pile exhalation	338
Waste rock pile exhalation	3
Total	3,829

[(a)] Ore grade = 0.1 percent U_3O_8. Annual production of ore and sub-ore = 2×10^5 MT, and waste rock = 2.2×10^4 MT.

The above-ground sources also emit radionuclides to air as particulates. The particulate emissions result from ore dumping and loading operations and wind erosion of storage piles. EPA has estimated that about 2E-2 Ci/y of uranium-238 and 3E-4 Ci/y of thorium-232 and each of their decay products would be emitted into the air at a large underground mine (EPA83b). An assessment of the health risks from these emissions showed that the risks from the particulate emissions were much smaller (a factor of 100 less) than the risks from radon-222 emissions (EPA83b). Therefore, the health risk assessment presented in the subsequent sections of this chapter will be limited to radon-222 emissions.

5.5 Reference Underground Uranium Mine

Table 5-6 describes the parameters of the reference mine which are used to estimate the radon-222 emissions to the atmosphere and the resulting health impacts. These parameters were chosen primarily from information in Tables 5-7 and 5-8. The reference mine has 5 vents in the configuration as shown in Figure 5-4.

Table 5-6. Reference underground uranium mine

Parameter	Value
Ore grade	0.22 percent U_3O_8
Ore production	112,000 tons/y
Days of operation	250 days/y
Number of vents	5
Vent height(a)	3 meters
Radon emissions	11,000 Ci/y(b)

(a) In estimating radon-222 concentrations in Table 5-9 for releases with plume rise, the following vent parameters were used: vent diameter is 1.5 meters, exit velocity is 16.2 meters/sec, and the exit temperature is 287°K (Drc84).

(b) 2,200 Ci/y from each vent.

Table 5-7. Summary of radon-222 emissions by age of underground uranium mine (Ja80)

	New mines		Old mines	
Mine	Age (years)	Radon-222 emissions (Ci/y)	Age (years)	Radon-222 emissions (Ci/y)
A	3	7,400	–	–
B	9	4,500	–	–
C	9	4,600	–	–
D	7	3,600	–	–
E	–	–	21	29,800
F	–	–	20	9,400
G	4	1,800	–	–
H	–	–	21	15,200
J	–	–	20	7,900
K	–	–	19	6,400
L	–	–	29	1,400
R	–	–	20	14,800
U	4	900	–	–
V	2	1,000	–	–
Y	6	17,500	–	–
Z	–	–	17	2,600
Average	6	5,200	21	10,900

(a) Data from measurements made in 1978 and 1979.

Table 5-8. Estimated ore production of selected mines, 1982 (Brb84)

Mine	Estimated 1982 production (10^3 tons/y)
New Mines (Mines less than 10 years old)	
King Solomon	38.0
Velvet	51.6
Tony M	137.6
Hack Canyon	63.1
Pidgeon	(a)
Kanab North	(a)
La Sal	81.7
Hecla	14.8
Big Eagle	16.6
Golden Eagle	(a)
Mt. Taylor	328.5
Old Church Rock	28.6
Church Rock-East	72.3
Kerr-McGee	
Section 19	127.2
Nose Rock	(a)
Mariano Lake	36.8
Average	62
Old Mines (10 years or more)	
Sunday	41.7
Dermo-Snyder	58.5
Wilson-Silverbell	16.5
Lisbon	73.3
Sheep Mtn.	0
Church Rock-NE	171.9
Church Rock-1	176.8
Kerr-McGee	
Section 30-East	119.5
Section 30-West	132.4
Section 35	195.1
Section 36	111.2
Homestake	
Section 23	208.9
Section 25	67.9
Schwartzwalder	198.8
Average	112

(a) Not operational.

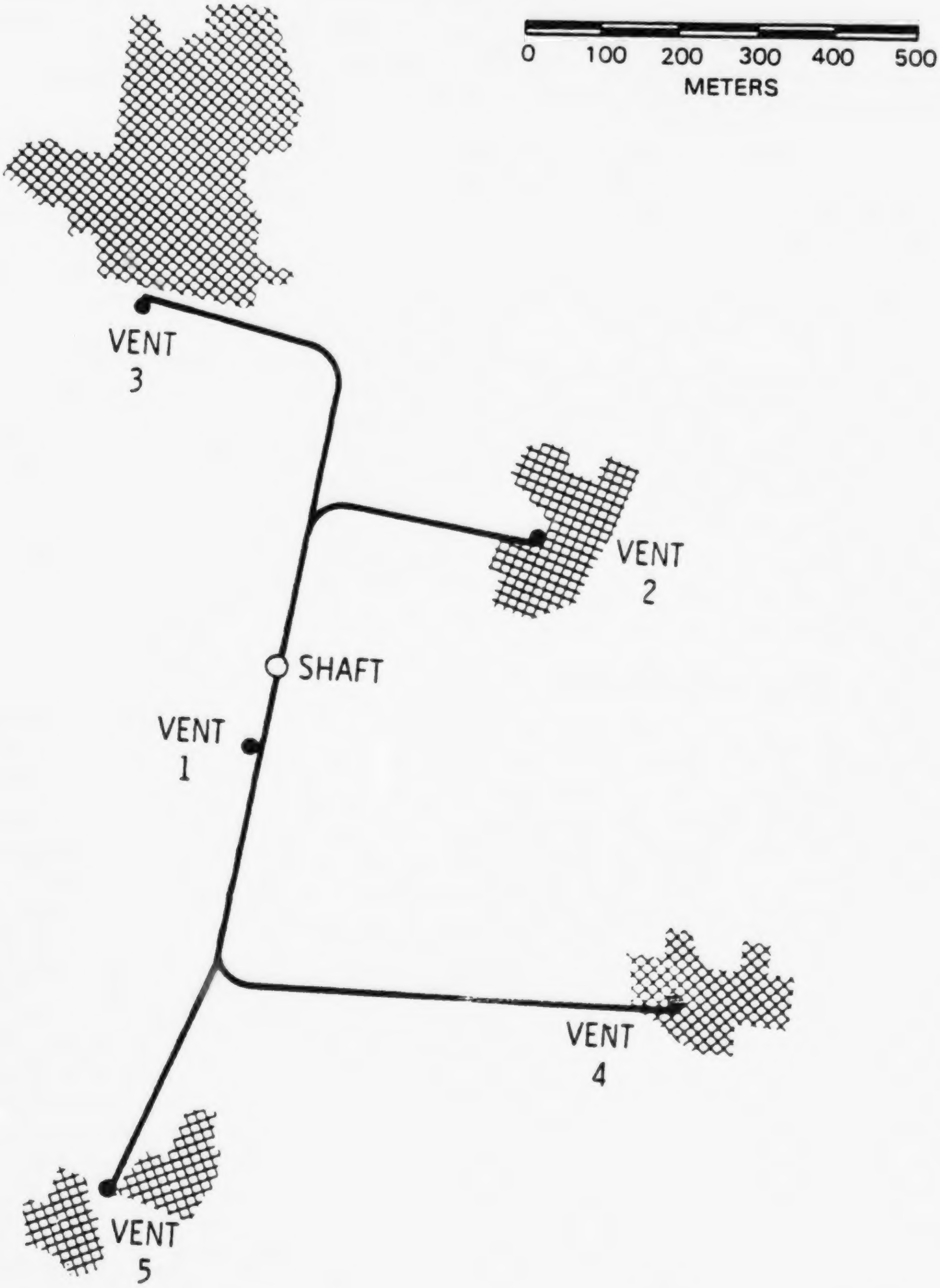

0
100
200
300
400
500
METERS
VENT 3
VENT 2
SHAFT
VENT 1
VENT 4
VENT 5

Figure 5-4. Reference underground mine.

5.6 Health Impact Assessment of the Reference Underground Uranium Mine

The lifetime risk to nearby individuals and the number of fatal cancers per year of operation due to radon-222 emissions from the reference underground uranium mine are presented in this section.

The risks to nearby individuals are treated in more detail than the population risks because risks to nearby individuals can be relatively high. These exposures generally occur in structures built around the mines. Radon-222 enters the building and decays into other radionuclides which become attached to dust particles in the air. The concentration of these radionuclides builds up in the air within the structures.

EPA estimated the health risks from radon-222 emissions from uranium mines using the general assumptions discussed in Volume I of this report. The actual risk to nearby individuals may differ from these estimates because the circumstances involving the exposure may differ significantly from the assumptions used to make the estimates. For example, because mines have a limited lifetime (10 to 20 years), the period of exposure is probably less in real cases than assumed in the models. Furthermore, since the risk is due primarily to the radioactive decay products of radon which build up indoors, these estimates may need to be corrected for occupancy times.

Risks to Nearby Individuals

In assessing the health risks to individuals living near underground uranium mines, an evaluation was made of a series of vents from a single mine, (i.e., the reference mine), and multiple vents from mines which are close together. The radon-222 concentrations in air near an underground mine are highly dependent upon a number of other factors. In addition to emission rates and meteorological parameters, these would include the spatial distribution of the vents, the orientation of the vents (vertical or horizontal), and the momentum flux of the exhaust air (velocity times flow rate). Plume rise from the momentum flux can significantly affect the ground level radon-222 concentrations near the mine vents. Discharges through horizontal vents will have little or no plume rise while discharges through vertical vents will usually have a significant amount of plume rise. The extent to which plume rise actually affects the ground level radon-222 concentrations near underground uranium mines is somewhat uncertain because of limited information on vent configurations and momentum fluxes. In addition, the relatively low height of the vent releases makes it uncertain that the computed plume rise will be realized in all cases. Near-release influences, such as buildings, walls, hills, and vegetation, can easily change local flow characteristics so that downwash of the plume occurs. Even when downwash does not occur, such objects increase local dispersion and will tend to decrease the plume rise effect. To show the range of potential radon-222 concentrations which would exist near an underground uranium mine, the ground level concentrations resulting from emissions from the reference mine were calculated for both ground level (all horizontal vents, i.e., no plume rise) and an elevated release (all vertical vents with plume rise). A ground level release with no plume rise represents a worst case assumption in terms of the computed ground level radon-222 concentrations. A release with plume rise represents a lower bound case for computed radon-222 concentrations. The radon concentrations computed with these two assumptions will cover the range of concentrations which can result from various local influences on plume rise.

Table 5-9 shows the estimated radon-222 concentrations and resulting working levels and lifetime fatal cancer risks at various distances from the shaft of the reference mine for releases with and without plume rise. The most likely radon-222 concentrations at these locations will fall somewhere within the range of values shown. These concentrations were computed using EPA's Industrial Source Complex Long Term Model (Drc84).

The estimated concentrations from ground level releases shown in Table 5-9 for distances at 500 and 1000 meters from the mine shaft are worst case situations with locations sited between a series of mine vents or relatively close (within a few hundred meters) to one of the vents where all of the vents involved are horizontal (i.e., no plume rise). It is unlikely at the present time that such extremely high concentrations actually exist near an underground uranium mine or that any individual is actually exposed to these high levels. However, as shown in Table 5-13, several hundred people are living within 1000 meters of underground uranium mine shafts, and these people are estimated to be exposed to increased radon-222 concentrations somewhere within the range of values shown for these locations in Table 5-9.

Table 5-10 shows estimated equilibrium ratios for radon at various distances assuming a wind speed of 1 m/sec from the uranium mine. Estimates of the radon-222 concentration at various distances from an underground uranium mine with five vents emitting 11,000 Ci/y of radon-222 are shown in Table 5-9 (Drc84). Also shown in this table are the estimated lifetime risks of fatal cancer to nearby individuals from the inhalation of radon-222 decay products produced (inside a house) by radon-222 concentrations. Table 5-11 shows the relationship between working levels and risk. The basic assumptions used in developing this table are discussed in Chapter 8, Volume I. This relationship is not linear because of competing risks of death from other causes. Using the relationship between equilibrium ratio and radon concentrations, the working level inside a structure at the specified distance is calculated as shown in Table 5-9. Table 5-11 is then used to estimate the lifetime risk for a person living in a structure 75 percent of the time near these sites.

To evaluate the extent to which emissions from multiple mines located close together will influence the radon-222 concentrations in

Table 5-9. Estimates of working levels and risk of fatal cancer in buildings at selected distances from the reference underground uranium mine(a)

	Ground level release				Release with plume rise			
Distance(b) (meters)	Radon-222(c) (pCi/L)	Working levels	Lifetime risk to nearby individuals(d)		Radon-222(c) (pCi/L)	Working levels	Lifetime risk to nearby individuals(d)	
500	27.6	.113	1E-1	(5E-2)	0.4	.0016	2E-3	(8E-4)
1,000	10.2	.045	5E-2	(2E-2)	0.4	.0019	2E-3	(9E-4)
2,000	2.2	.011	1E-2	(5E-3)	0.2	.001	1E-3	(5E-4)
3,000	1.1	.006	7E-3	(3E-3)	0.2	.001	1E-3	(5E-4)
5,000	0.5	.003	3E-3	(2E-3)	0.1	.0006	7E-4	(3E-4)
7,000	0.3	.002	2E-3	(1E-3)	0.1	.0006	7E-4	(3E-4)
10,000	0.2	.001	1E-3	(5E-4)	0.1	.0006	7E-4	(3E-4)

(a) The lifetime risks were estimated depending on the equilibrium ratios calculated in the structures at various distances (See Table 5-10).

(b) The distance is measured from the shaft of the model mine. This is different from the distances shown in Tables 5-8 and 5-9 of the Draft Background Information Document (EPA83d) where the distances listed were distances from vent 5.

(c) Drc84.

(d) The values in the first column are based on BEIR-3, NRPB, and EPA models (see Chapter 8, Volume I). The values in parentheses are based on UNSCEAR and ICRP risk estimates (see Chapter 8, Volume I).

Table 5-10. Outdoor and indoor equilibrium ratios for radon emitted from an underground uranium mine at selected distances from the mine(a)

Distance (meters)(b)	Time for plume to reach distance (min)	Equilibrium ratio (Outdoors)	Equilibrium ratio (Indoors)(c)
500	8.3	0.15	.41
1,000	16.7	0.26	.44
2,000	33.3	0.45	.50
3,000	50.0	0.60	.55
5,000	83.3	0.80	.62
7,000	116.7	0.90	.65
10,000	166.7	0.96	.67

(a) A wind speed of 1 m/sec is assumed.

(b) The distance is measured from the shaft of the model mine.

(c) This calculation assumes a ventilation rate of 1 h^{-1} and an effective plate out rate of 1 h^{-1} (EPA83c).

Table 5-11. Relationship between working level and risk of fatal cancer

Working level	Lifetime risk[a]	
.0001	1E-4	(5E-5)
.001	1E-3	(5E-4)
.01	1E-2	(5E-3)
.1	1E-1	(5E-2)

(a)The values in the first column are based on BEIR-3, NRPB, and EPA models (see Chapter 8, Volume I). The values in parentheses are based on UNSCEAR and ICRP risk estimates (see Chapter 8, Volume I).

air, PNL carried out a modeling study using the Ambrosia Lake District of New Mexico as a "case study" (Drb81). Using a Gaussian diffusion model, estimates were made of the radon-222 concentrations in air resulting from emissions from 117 mine vents. Figure 5-5 shows the distribution of mine vents used in the study and Figure 5-6 the computed radon-222 concentrations (above background) in air for this region. Although these computed concentrations are only approximate values, because of the complexities of this modeling study, the results indicate that the radon-222 concentrations in an intensive underground uranium mining area will be significantly elevated above background. The vents are also the greatest sources of the radon concentrations in the immediate area of mining and milling activities. Another study of multiple mines done by PNL (Drc84) confirms these conclusions. The PNL also looked at the effect of plume rise on concentrations from multiple mines due to vertical vents. If it is assumed that all the vents in a multiple mine area are vertical (plume rise), the concentrations are much lower than if the vents are assured to be horizontal (ground level release).

Two measurement studies were also conducted in the Ambrosia Lake, New Mexico, area to determine the concentrations of radon around uranium mines and mills. The EPA conducted the first study in November 1975 (EPA75) at the request of the New Mexico Environmental Improvement Agency and found that ambient outdoor radon concentrations were in excess of typical background levels. It was suggested that a better definition of background levels in the area be determined and a thorough evaluation of specific source terms be conducted.

In 1978 the New Mexico Environmental Improvement Division conducted a two-year program (Bu83) to determine (1) sources of high concentrations of airborne radioactivity in uranium producing areas, (2) radioactivity levels due to background as well as levels associated with uranium milling and mining activities, and (3) if New Mexico

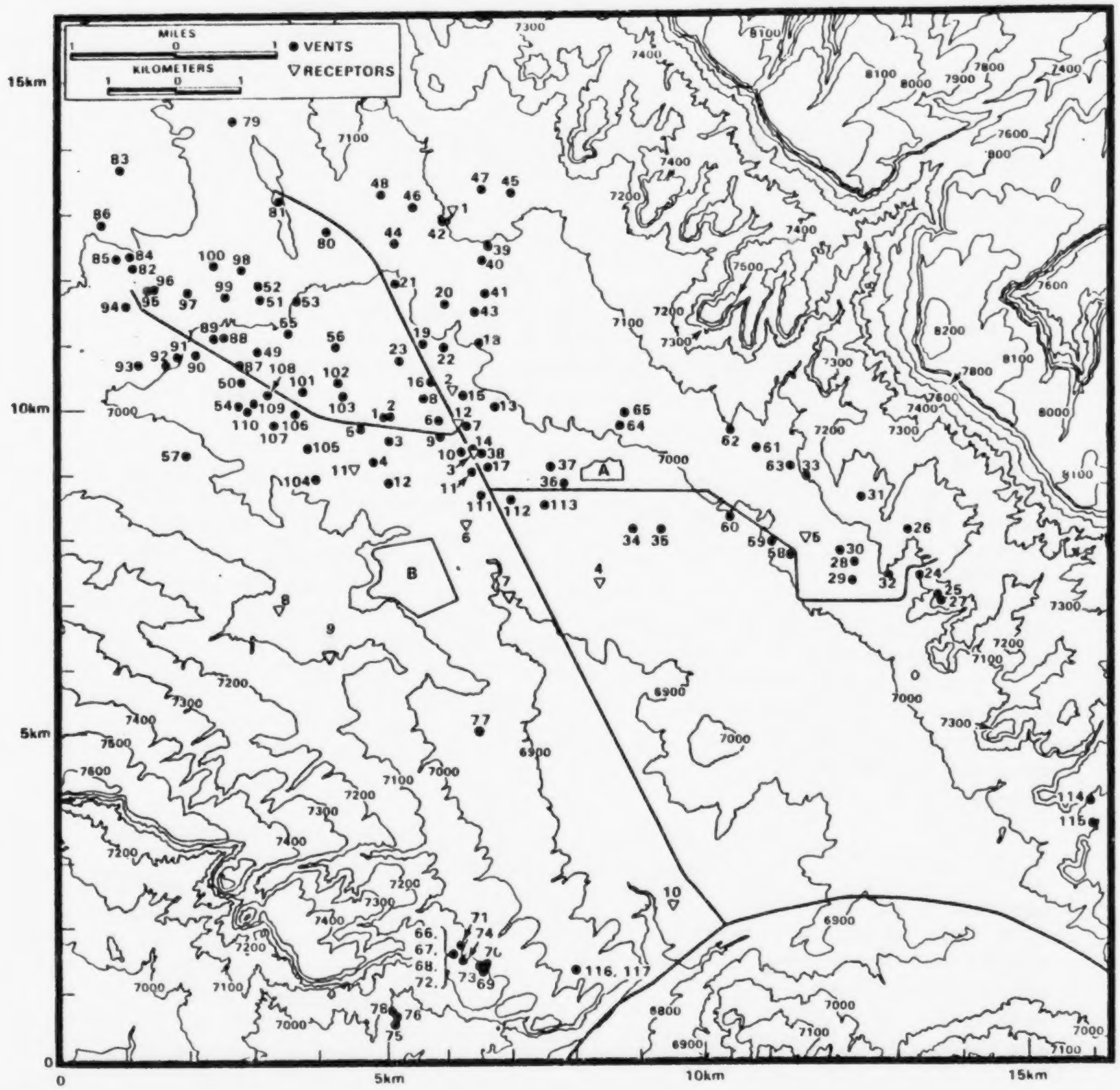

MILES
1 0 1
KILOMETERS
1 0 1
● VENTS
▽ RECEPTORS
A
B
0
5km
10km
15km
0
5km
10km
15km

Figure 5-5. Detailed map of mining area showing mine vent source.

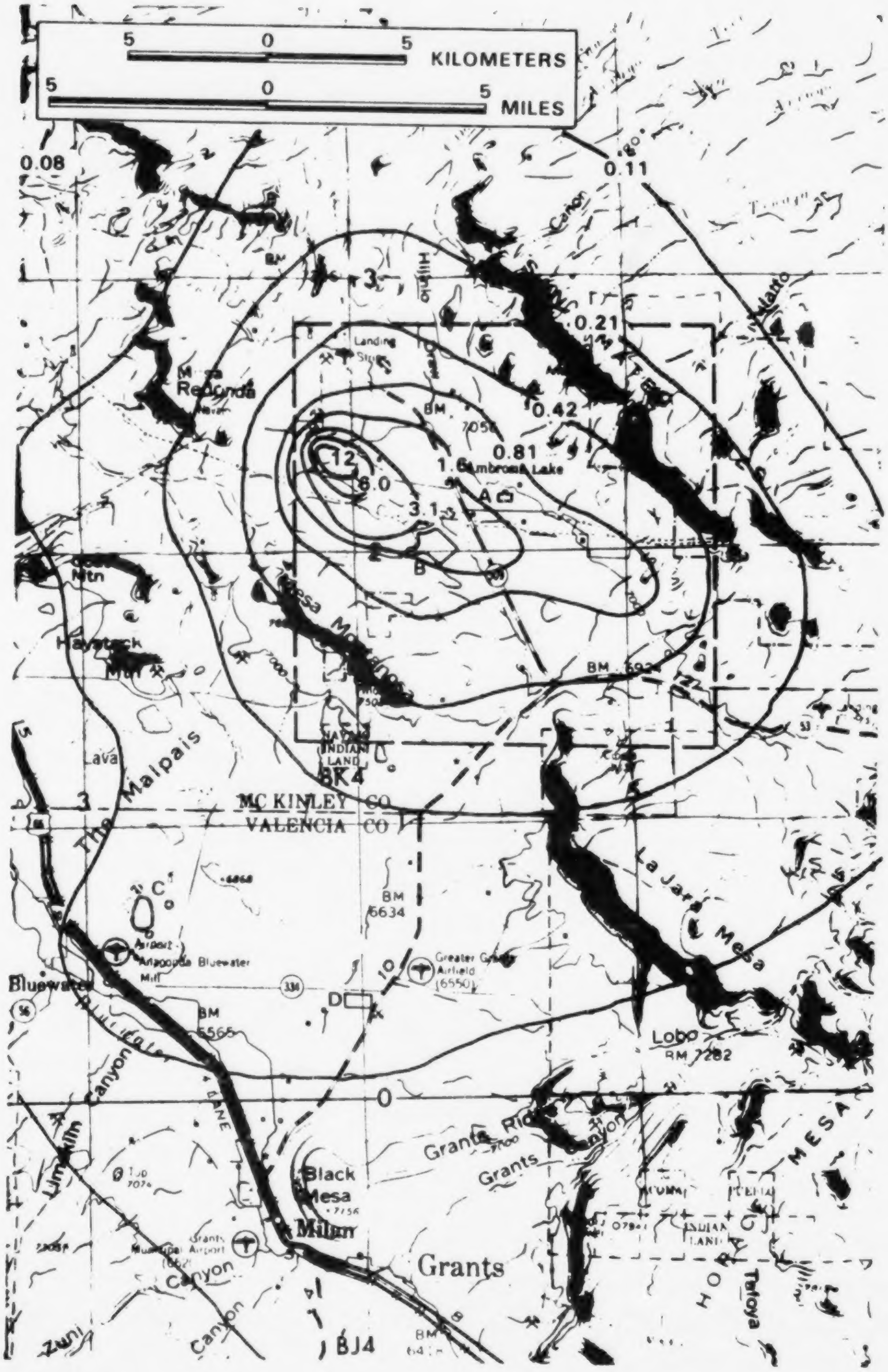

5 0 5 KILOMETERS
5 0 5 MILES
0.08
0.11
0.21
0.42
0.81
1.6
3.1
6.0
12
Landing Strip
BM 7050
Ambrosia Lake
A
B
C
D
Mesa Redonda
Haystack Mtn
Lava
The Malpais
Mesa Montanosa
NAVAJO INDIAN LAND
BK4
MC KINLEY CO
VALENCIA CO
La Jara Mesa
Lobo
BM 7282
BM 6634
BM 5565
Bluewater
Anaconda Bluewater Mill
Greater Grants Airfield (6550)
Black Mesa
Milan
Grants
Grants Municipal Airport
Zuni Canyon
Limekiln Canyon
Grants Canyon
Teloya
HORACE MESA
BJ4

Figure 5-6. Computed radon concentration map for region isopleths (pCi/L).

standards are being exceeded. Background radon concentrations were determined at six representative undisturbed locations within the Grants Mineral Belt. Uranium mines were found to be the primary cause of elevated radon concentrations in Ambrosia Lake. Ambient radon concentrations near uranium mines exceeded the New Mexico radiation standard for an individual member (3pCi/l) of the public at three of the nine locations in the study.

Population Risks

The radon decay product exposures and the number of fatal cancers per year of operation for the reference underground uranium mine are shown in Table 5-12. These estimates are for a site near Grants, New Mexico, with a regional population of 36,000 using AIRDOS-EPA to calculate the radon exposures (Appendix A). The number of fatal cancers per year of operation of the reference mine is estimated to be about 0.04 to the regional population and 0.08 to the national population.

The inert radon gas emitted from mines can be transported beyond the 50-mile regional cutoff. A trajectory dispersion model developed by NOAA (Tr79) has been used to estimate the national impact of radon emissions from the mine. This model calculates the potential radiation exposure to the U.S. population for radon released from four typical uranium processing locations. (Descriptions of these typical mill sites--Casper, Wyoming; Falls City, Texas; Grants, New Mexico; and Wellpinit, Washington--are given in (Tr79).) Only exposures taking place beyond the 50-mile regional limit are considered. Details of the model are given in He75. The model yields radon concentrations (pCi/L) in air which were converted to decay product concentrations by assuming that 100 pCi/L of radon corresponds to a decay product concentration of 0.7 WL.

Table 5-12. Annual radon-222 decay product exposures and number of fatal cancers to the population from radon-222 emissions from the reference underground uranium mine

Source	Regional population			National population		
	(Person-WL-y)	(Fatal cancers/y of operation)[(a)]		(Person-WL-y)	(Fatal cancers/y of operation)[(a)]	
Underground uranium mine	2.2	6E-2	(2E-2)	6.2	1E-1	(6E-2)

[(a)] The values in the first column are based on BEIR-3, NRPB, and EPA models (see Chapter 8, Volume I). The values in parentheses are based on UNSCEAR and ICRP risk estimates (see Chapter 8, Volume I).

5.7 Health Impact from Underground Uranium Mining

An estimate of the total health impact from radon-222 emissions from all underground uranium mining (using production values for 1982) may be made by multiplying the number of fatal cancers caused by emissions from the reference mine by the ratio of the amount of uranium produced by all underground mines to the amount produced by the reference mine. This ratio is about 25. The estimate for the regional population is about two fatal cancers/year and for the national population is about three fatal cancers/year.

5.8 Reduction of Exposures through Land Control

Rather than control radon emissions at the source, it may be more practical to limit the exposure to individuals near underground mines by controlling land near the vents to prevent people from living in houses in these areas. At the request of EPA, the Pacific Northwest Laboratory conducted a field study in January and February 1983 to determine the population, type of ownership, and cost of land around 30 large uranium mines (Brb83). These mines represented about 84 percent of the uranium production from underground mines at that time.

Table 5-13 shows the population data gathered from the PNL study. An estimate was made of all residents within 5 km of the mine shaft by locating all the residences on a map. The average 1980 census figure of residents per home in each county was used to estimate the population. If mines were close together, populations were evenly distributed among the mines according to the distances from the mines. Maps showing the distribution of population around these mines are located at the end of this chapter.

Table 5-14 represents the percent distribution of land ownership around the 30 surveyed mines. County tax assessors' records were reviewed for all properties within a 5-km radius of each mine. The ownership of the land was determined and percentages, according to three types of ownership (private, mine, or government), are shown for each mine. Land values for the private land were estimated from: (1) assessed valuations and applying applicable selling price to assessed valuation ratios, (2) estimates from local real estate agents, (3) information supplied by state and county assessors, and (4) local newspapers. The valuations were based on surface usage and rights only, since the mineral values would remain intact.

Table 5-15 summarizes the cost of the land around each mine. Since the land owned by the mine operator or a government agency can already be controlled, only costs to purchase private land were determined.

The Schwartzwalder mine near Denver, Colorado, is not included in the total cost of all surveyed mines shown in Table 5-15 because it is not a typical mine site. It is located near a large metropolitan area and the cost of the land is quite high since the land can be purchased or subdivided for mountain resort homes. The mine is also located in a mountainous region so that radon emissions may be confined in the immediate area of the mine and any land control which may be necessary would be relatively small.

The information in Tables 5-13 through 5-15 can be used to obtain a rough estimate of the cost to control land around underground uranium mines. The cost to control land within a 2-km radius of the mines surveyed is as follows:

Type of cost	Total cost (millions)	Yearly cost (millions)
Land cost (100 percent contingency with 10 percent yearly cost)	$15.0	$1.5
Structures (100 percent contingency with amortization over 5 years at 10 percent)	3.8	1.1
Relocation of 420 non-Indian residents ($5,000/person with amortization over 5 years at 10 percent)	2.1	0.6
Relocation of Indian residences ($18,000/person- 198 Indians, with amortization over 5 years at 10 percent)	3.6	1.1
Total yearly cost		4.3

The 10 percent yearly cost assumes that the land value does not change and thus is a nondepreciated asset. The present worth factor for amortization over a 5 year period using a 10 percent interest rate is 0.264. This is rounded to 0.3 to account for taxes.

Assuming that the 29 mines produced 84 percent of the underground mine yearly production of 6,200 tons of U_3O_8 for the industry (Brb83), the cost of land control per pound of U_3O_8 can be estimated as follows:

$$\text{cost/lb } U_3O_8 = \frac{\$4,300,000}{(.84)(6,200)(2,000)} = \$0.41/\text{lb } U_3O_8$$

If production costs for U_3O_8 are $30/lb, the increased cost to the industry would be 1 percent of the cost of production. In a similar manner, it can be calculated that the cost per ton of ore would be $1.82/ton of ore. This can then be compared to the cost of radon control technologies in Table 5-3.

Table 5-13. Population around selected underground uranium mines (Brb84)

Mine	State	Distance from mine (km)					
		0-1/2	0-1	0-2	0-3	0-4	0-5
Sunday	Colo.	0	0	0	0	0	0
King Solomon	Colo.	0	0	0	0	0	0
Velvet	Utah	0	0	0	0	0	0
Tony M	Utah	0	0	0	0	0	0
Hack Canyon	Arizona	1	1	1	1	1	1
Pidgeon	Arizona	0	0	0	0	0	0
Kanab North	Arizona	0	0	0	0	0	0
Dermo-Snyder	Colo./Utah	0	5	21	49	67	83
Wilson-Silverbell	Utah/Colo.	0	0	0	12	20	23
Lisbon	Utah	0	0	0	4	44	44
LaSal	Utah	0	0	53	101	194	194
Hecla	Utah	16	16	20	40	73	73
Big Eagle	Wyoming	0	0	0	0	0	0
Golden Eagle	Wyoming	0	0	0	6	6	6
Sheep Mtn.	Wyoming	0	0	0	0	0	12
Mt. Taylor	New Mexico	0	100	317	336	336	336
Old Church Rock	New Mexico	9	9	70	139	187	364
Church Rock-NE	New Mexico	0	11	22	26	31	31
Church Rock-1	New Mexico	0	11	22	27	31	31
Church Rock-East	New Mexico	0	0	9	57	70	131
Kerr-McGee Sec 30 East	New Mexico	3	3	3	3	3	3
Kerr-McGee Sec 30 West	New Mexico	0	5	5	5	5	6
Kerr-McGee Sec 19	New Mexico	0	0	0	4	4	4
Kerr-McGee Sec 35	New Mexico	0	0	0	0	0	0
Kerr-McGee Sec 36	New Mexico	0	0	0	0	0	0

Table 5-13. Population around selected underground uranium mines (Brb84) (Continued)

Mine	State	Distance from mine (km)					
		0-1/2	0-1	0-2	0-3	0-4	0-5
Homestake Sec 23	New Mexico	0	0	0	3	3	4
Homestake Sec 25	New Mexico	0	0	0	0	0	0
Nose Rock[(a)]	New Mexico	0	0	0	0	26	35
Mariano Lake	New Mexico	13	44	75	196	274	352
Schwartz-walder[(a)]	Colorado	3	3	63	102	136	147
Totals		42	205	618	1,009	1,375	1,733

(a) The population around this mine is not included in the total because the location is not typical of the industry.

Table 5-14. Percent distribution of land ownership around selected underground uranium mines (Brb84)

Mine	Distance from mine (km)[a]					
	0-1/2	0-1	0-2	0-3	0-4	0-5
Sunday	0/0/100	0/0/100	0/0/100	3/1/97	8/1/91	10/1/89
King Solomon	0/0/100	0/2/98	0/5/95	0/3/97	0/3/97	0/3/97
Velvet	14/0/86	10/0/90	6/0/94	12/0/88	24/0/76	27/0/73
Tony M	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100
Hack Canyon	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100
Pidgeon	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100
Kanab North	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100	1/0/99
Dermo-Snyder	84/0/16	87/0/13	84/0/16	89/0/11	85/0/15	81/0/19
Wilson-Silverbell	80/0/20	95/0/5	95/0/5	94/0/6	91/0/9	81/0/19
Lisbon	0/0/100	0/0/100	6/0/94	17/2/81	21/1/78	16/1/83
LaSal	8/0/92	25/0/75	34/0/66	41/0/59	34/0/66	26/0/74
Hecla	25/0/75	25/0/75	48/0/52	37/0/63	28/0/72	21/0/79
Big Eagle	0/100/0	0/88/12	0/80/20	0/8/92	0/5/95	1/3/96
Golden Eagle	60/20/20	89/7/4	85/3/2	94/1/5	91/1/8	90/1/9
Sheep Mtn.	30/45/25	18/42/40	5/28/69	2/18/80	4/11/85	12/8/80
Mt. Taylor	75/19/6	58/26/16	58/16/29	45/13/42	39/10/51	39/7/54
Old Church Rock	0/0/100	0/0/100	0/0/100	0/0/100	2/0/98	3/0/97
Church Rock NE	0/0/100	0/7/93	0/23/77	0/13/87	0/8/92	0/5/95
Church Rock #1	0/0/100	0/7/93	0/23/77	0/13/87	0/8/92	0/5/95
Church Rock East	0/0/100	0/7/93	0/6/94	3/4/93	5/2/93	3/1/96
Kerr-McGee Sec 30 East	11/89/0	4/91/5	2/70/28	4/78/18	10/79/11	13/77/10
Kerr-McGee Sec 30 West	11/89/0	24/76/0	17/72/11	16/69/15	22/66/12	27/57/16
Kerr-McGee Sec 19	0/100/0	23/77/0	46/39/15	45/39/16	32/37/31	29/38/33
Kerr-McGee Sec 35	0/100/0	0/85/15	8/59/33	14/55/31	10/57/33	14/52/34
Kerr-McGee Sec 36	5/42/53	14/22/64	27/14/59	36/8/56	36/5/59	39/3/58

See footnotes at end of table.

Table 5-14. Percent distribution of land ownership around selected underground uranium mines (Brb84) (Continued)

Mine	Distance from mine (km)[a]					
	0-1/2	0-1	0-2	0-3	0-4	0-5
Homestake Sec 23	74/0/26	68/0/32	61/6/33	50/18/32	47/17/36	53/12/35
Homestake Sec 25	100/0/0	85/0/15	59/0/41	58/1/41	50/2/48	43/10/47
Nose Rock	0/50/50	0/50/50	0/45/55	0/41/59	0/38/62	0/35/65
Mariano Lake	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100
Schwartz-walder[b]	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0
Average	20/22/58	22/20/58	22/17/61	23/13/64	22/12/66	22/11/67

[a] The first figure in the column represents the percent of private land, the second is land owned by the mine owner, and the third shows the percentage of land owned by a government agency. For example, in the case of the Sunday mine (at 0-1/2 km), 100 percent is owned by the government.

[b] The land ownership percentage for the Schwartzwalder mine was not included in the average for all the mines since the location is not typical of the industry.

Table 5-15. Estimated value of private land around selected underground uranium mines(a) (Brb84)
(In thousands)

Mine	Distance from mine (km)					
	0-1/2	0-1	0-2	0-3	0-4	0-5
Sunday	NA	NA	NA	48.0	208.0	384.0
King Solomon	NA	NA	NA	NA	NA	NA
Velvet	5.5	16.0	36.0	172.8	603.2	1,048.0
Tony M	NA	NA	NA	NA	NA	NA
Hack Canyon	NA	NA	NA	NA	NA	NA
Pidgeon	NA	NA	NA	NA	NA	NA
Kanab North	NA	NA	NA	NA	NA	(b)
Dermo-Snyder	79.7	260.4	922.6	1,852.1	3,028.9	4,432.8
Wilson-Silverbell	39.1	186.4	535.8	1,667.2	2,861.6	3,968.7
Lisbon	NA	NA	50.0	306.0	810.5	810.5
LaSal	4.0	228.4	920.9	1,427.8	2,484.5	2,534.5
Hecla	36.8	147.3	380.0	691.0	965.9	1,000.5
Big Eagle	NA	NA	NA	NA	NA	NA
Golden Eagle	35.4	209.0	796.2	2,121.0	3,584.0	5,231.0
Sheep Mtn.	18.0	42.3	42.3	42.3	150.0	898.0
Mt. Taylor	39.6	391.5	2,523.7	2,834.2	3,227.4	3,918.8
Old Church Rock	NA	NA	NA	NA	543.3	1,443.1
Church Rock NE	NA	NA	NA	NA	NA	NA
Church Rock-1	NA	NA	NA	NA	NA	NA
Church Rock-East	NA	NA	NA	122.2	355.6	355.6
Kerr-McGee Sec 30 East	35.0	35.0	35.0	53.5	147.6	240.0
Kerr-McGee Sec 30 West	31.1	132.2	147.8	157.9	194.8	235.1
Kerr-McGee Sec 19	NA	194.4	844.8	1,229.4	1,405.1	1,532.8
Kerr-McGee Sec 35	NA	NA	37.0	137.8	168.0	336.0
Kerr-McGee Sec 36	3.4	23.5	124.3	336.0	588.0	977.8

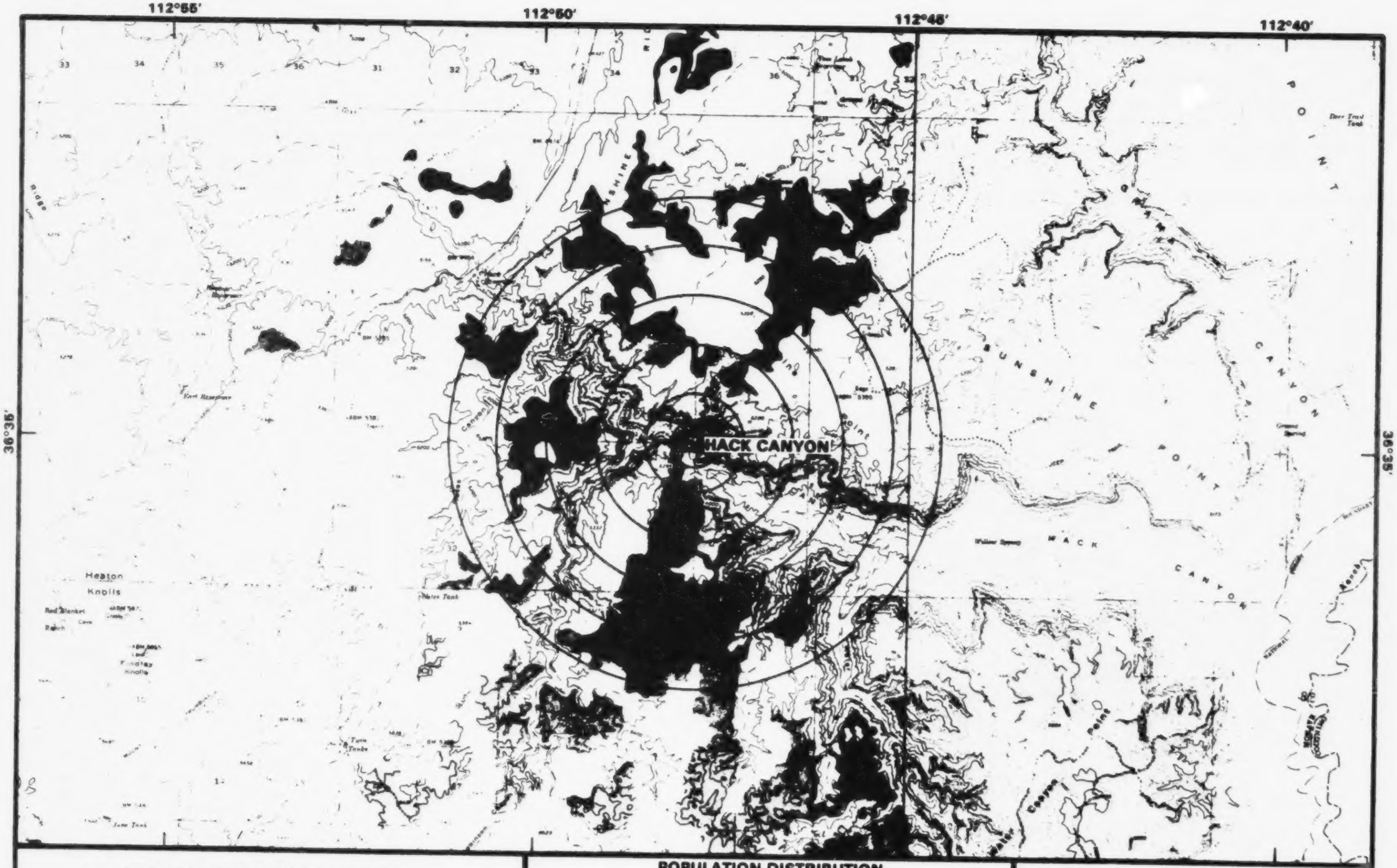
See footnotes at end of table.

Table 5-15. Estimated value of private land around selected underground uranium mines[a] (Brb84) (Continued)
(In thousands)

Mine	Distance from mine (km)					
	0-1/2	0-1	0-2	0-3	0-4	0-5
Homestake Sec 23	217.8	528.0	994.1	1,158.7	1,485.2	2,361.8
Homestake Sec 25	295.6	622.2	987.8	1,478.0	1,632.2	1,645.6
Nose Rock	NA	NA	NA	NA	NA	NA
Mariano Lake	NA	NA	NA	NA	NA	NA
Schwartz-walder[c]	880.0	3,400.0	15,200.0	33,600.0	58,400.0	89,200.0
Totals	841.0	3,016.6	9,378.2	15,835.8	24,443.8	33,354.6

[a] Includes cost of land (80 percent) and structures (20 percent).
[b] About 100 acres of patented mining claims.
[c] The costs for this mine were not included in the total costs because the location and cost of land is not typical of the industry.

NA Not assessed; all land owned by either the mine owner or the government.


112°55′
112°50′
112°45′
112°40′
36°35′
36°35′
HACK CANYON
SUNSHINE
POINT
CANYON
SUNSHINE
POINT
HACK
CANYON
Heaton
Knolls
Red Blanket
Findlay
Knolls

HACK CANYON MINE
MOHAVE COUNTY, ARIZONA

ALL OCCUPIED DWELLINGS; MINE SHAFT LOCATION; POPULATION DISTRIBUTION

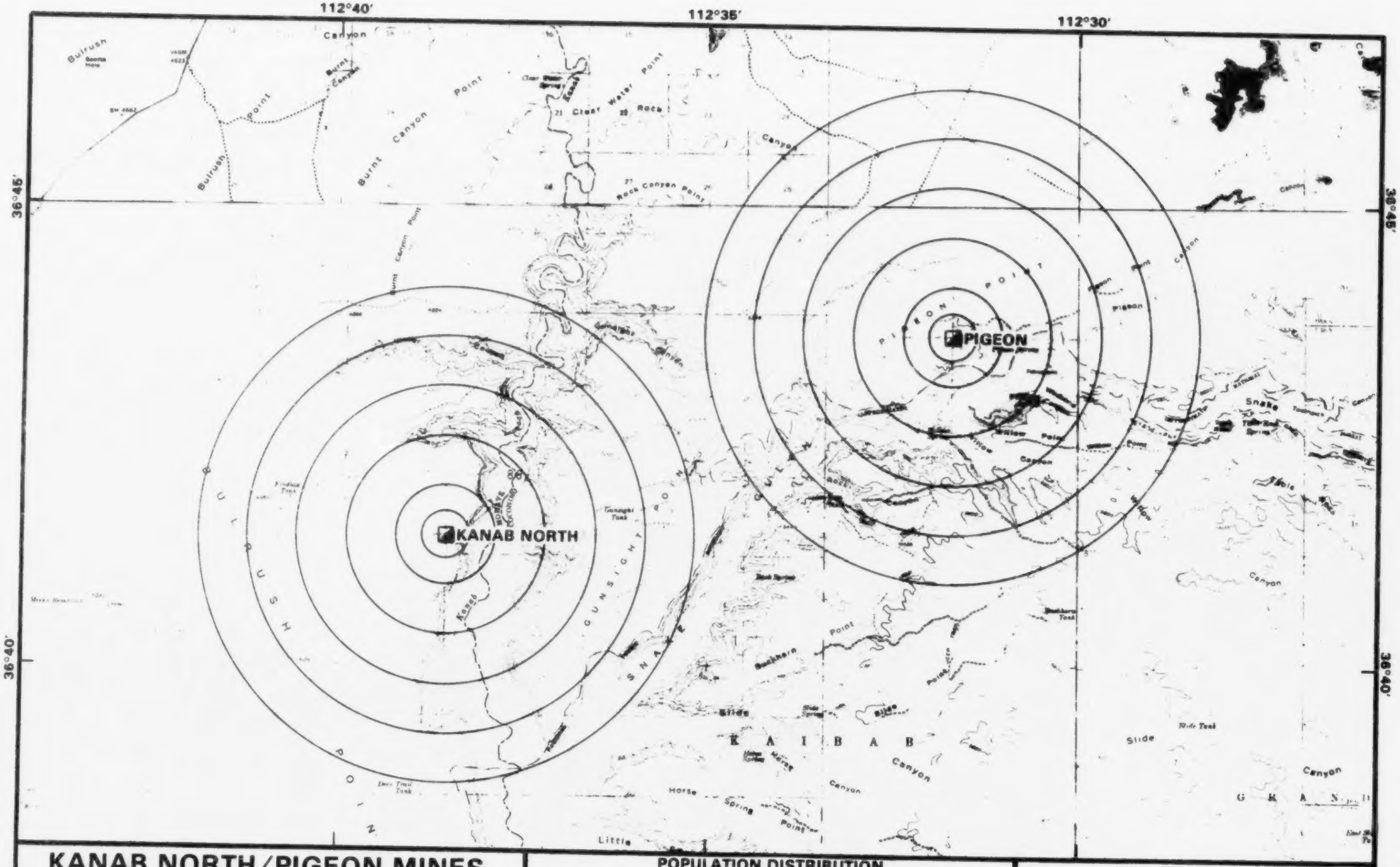
POPULATION DISTRIBUTION

MINE	0-1/2 km	0-1 km	0-2 km	0-3 km	0-4 km	0-5 km
HACK CANYON	1	1	1	1	1	1

0
1
2
3
4
MILES
0
1
2
3
4
5
6
KILOMETERS

LEGEND:

- ● SINGLE OCCUPIED DWELLING
- ② OCCUPIED DWELLING CLUSTER (NO. IS STRUCTURES)
- ◩ MINE SHAFT


112°40'
112°35'
112°30'
36°45'
36°40'
PIGEON
KANAB NORTH
PIGEON POINT
GUNSIGHT POINT
BULRUSH POINT
SNAKE
KAIBAB
Burnt Canyon Point
Rock Canyon Point
Clear Water Point
Bulrush
Kanab
Horse Spring Point
Slide
Canyon
Little

KANAB NORTH/PIGEON MINES MOHAVE COUNTY AND COCONINO COUNTY, ARIZONA

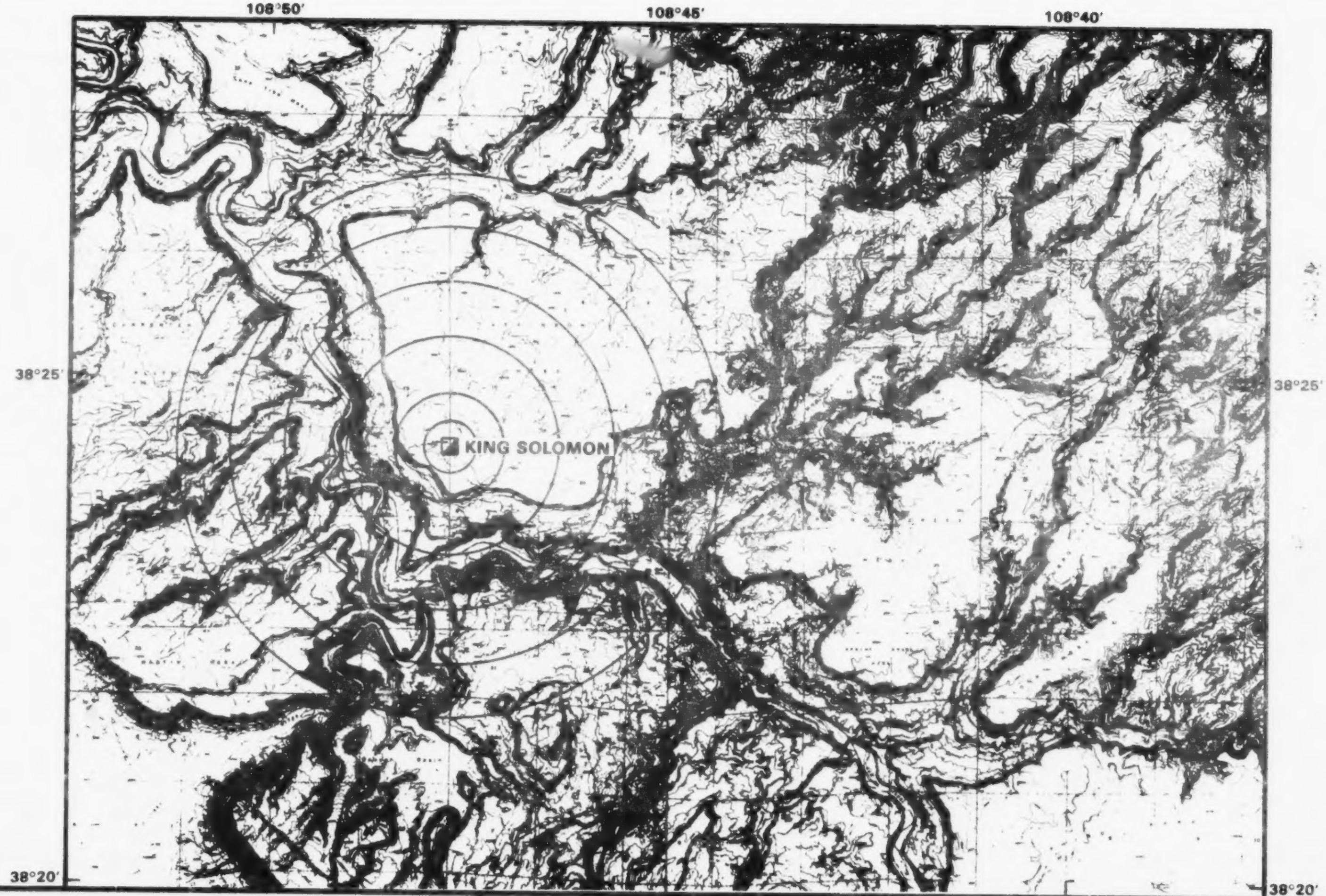
ALL OCCUPIED DWELLINGS; MINE SHAFT LOCATIONS; POPULATION DISTRIBUTION

POPULATION DISTRIBUTION

MINE	0-1/2 km	0-1 km	0-2 km	0-3 km	0-4 km	0-5 km
KANAB NORTH	0	0	0	0	0	0
PIGEON	0	0	0	0	0	0

0 1 2 3 4 MILES
0 1 2 3 4 5 6 KILOMETERS

LEGEND:
- ● SINGLE OCCUPIED DWELLING
- ② OCCUPIED DWELLING CLUSTER (NO. IS STRUCTURES)
- ◪ MINE SHAFT

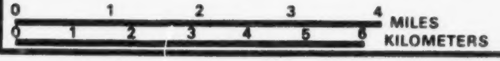

108°50'
108°45'
108°40'
38°25'
38°25'
38°20'
38°20'
KING SOLOMON

KING SOLOMON MINE
MONTROSE COUNTY, COLORADO

ALL OCCUPIED DWELLINGS; MINE SHAFT LOCATION; POPULATION DISTRIBUTION

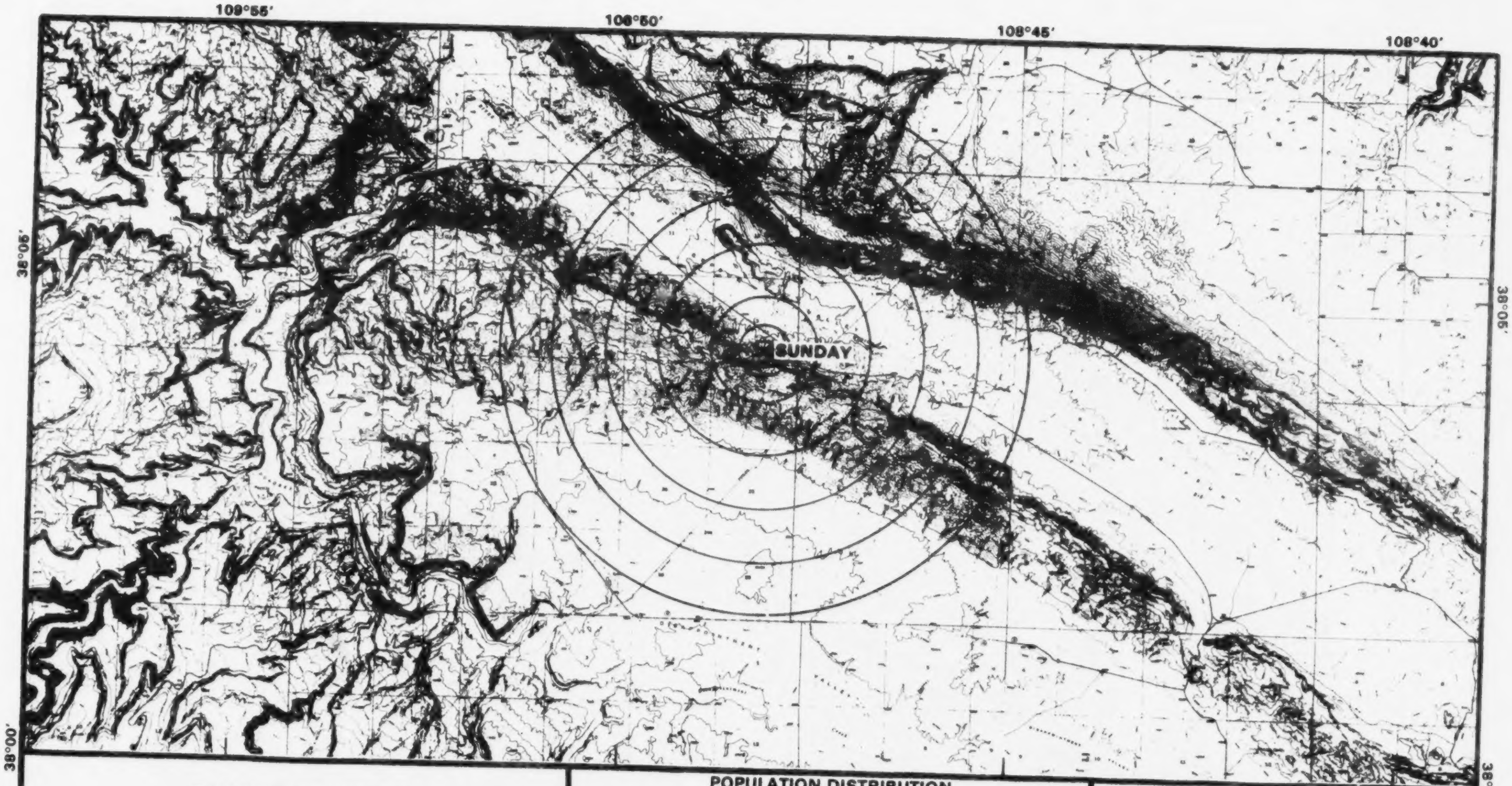
POPULATION DISTRIBUTION

MINE	0-1/2 km	0-1 km	0-2 km	0-3 km	0-4 km	0-5 km
KING SOLOMON	0	0	0	0	0	0


0
1
2
3
4
MILES
0
1
2
3
4
5
6
KILOMETERS

LEGEND:

- ● SINGLE OCCUPIED DWELLING
- ② OCCUPIED DWELLING CLUSTER (NO. IS STRUCTURES)
- ◪ MINE SHAFT


109°55′
108°50′
108°45′
108°40′
38°05′
38°05′
38°00′
38°00′
SUNDAY

SUNDAY MINE
SAN MIGUEL COUNTY, COLORADO

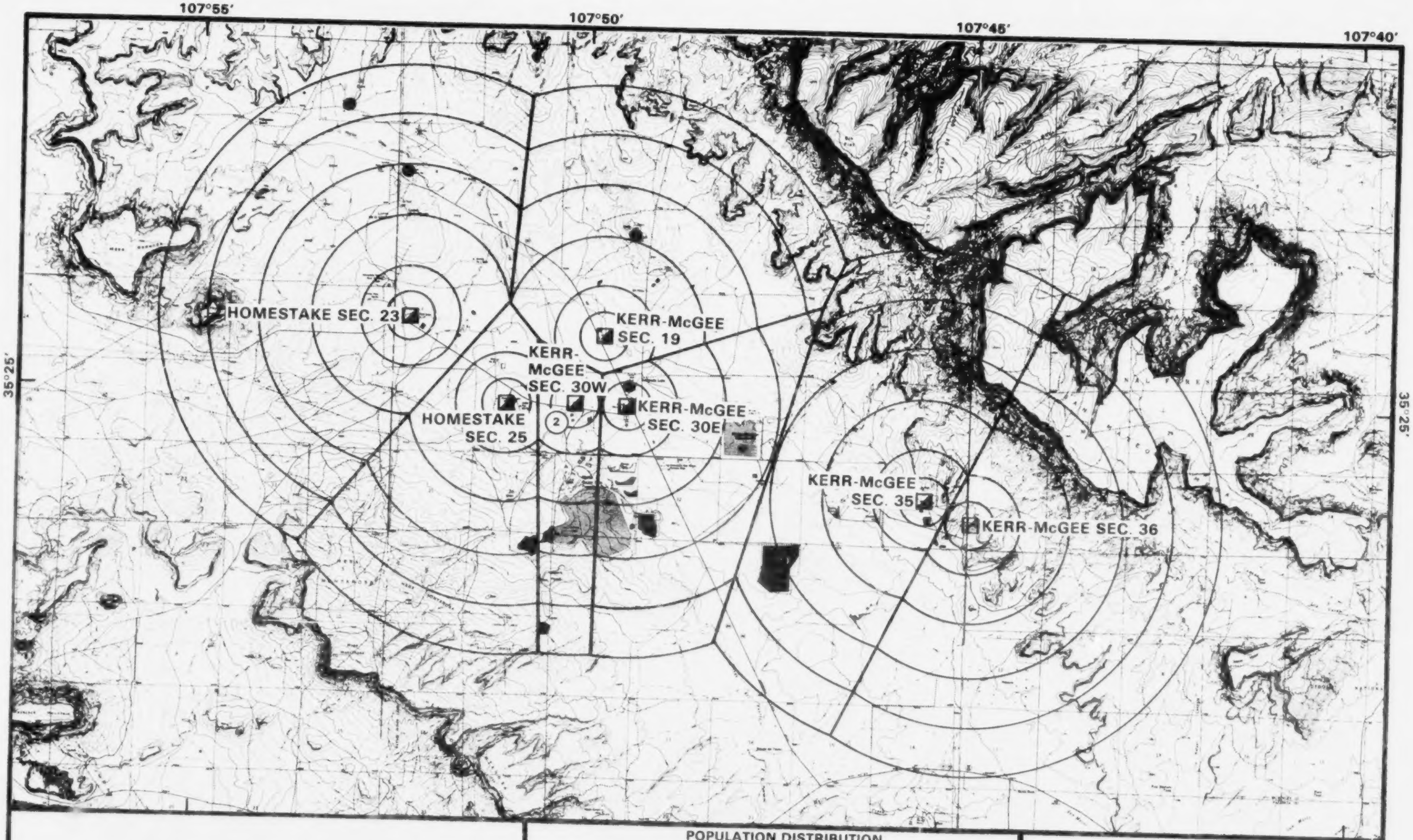
ALL OCCUPIED DWELLINGS, MINE SHAFT LOCATION; POPULATION DISTRIBUTION

POPULATION DISTRIBUTION

MINE	0-1/2 km	0-1 km	0-2 km	0-3 km	0-4 km	0-5 km
SUNDAY	0	0	0	0	0	0

0 1 2 3 4 MILES
0 1 2 3 4 5 6 KILOMETERS

LEGEND:
- ● SINGLE OCCUPIED DWELLING
- ② OCCUPIED DWELLING CLUSTER (NO. IS STRUCTURES)
- ◪ MINE SHAFT

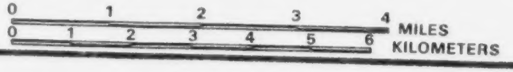

107°55'
107°50'
107°45'
107°40'
35°25'
35°25'
HOMESTAKE SEC. 23
KERR-McGEE SEC. 19
KERR-McGEE SEC. 30W
HOMESTAKE SEC. 25
2
KERR-McGEE SEC. 30E
KERR-McGEE SEC. 35
KERR-McGEE SEC. 36

AMBROSIA LAKE AREA
McKINLEY COUNTY, NEW MEXICO

ALL OCCUPIED DWELLINGS; MINE SHAFT LOCATIONS; POPULATION DISTRIBUTION

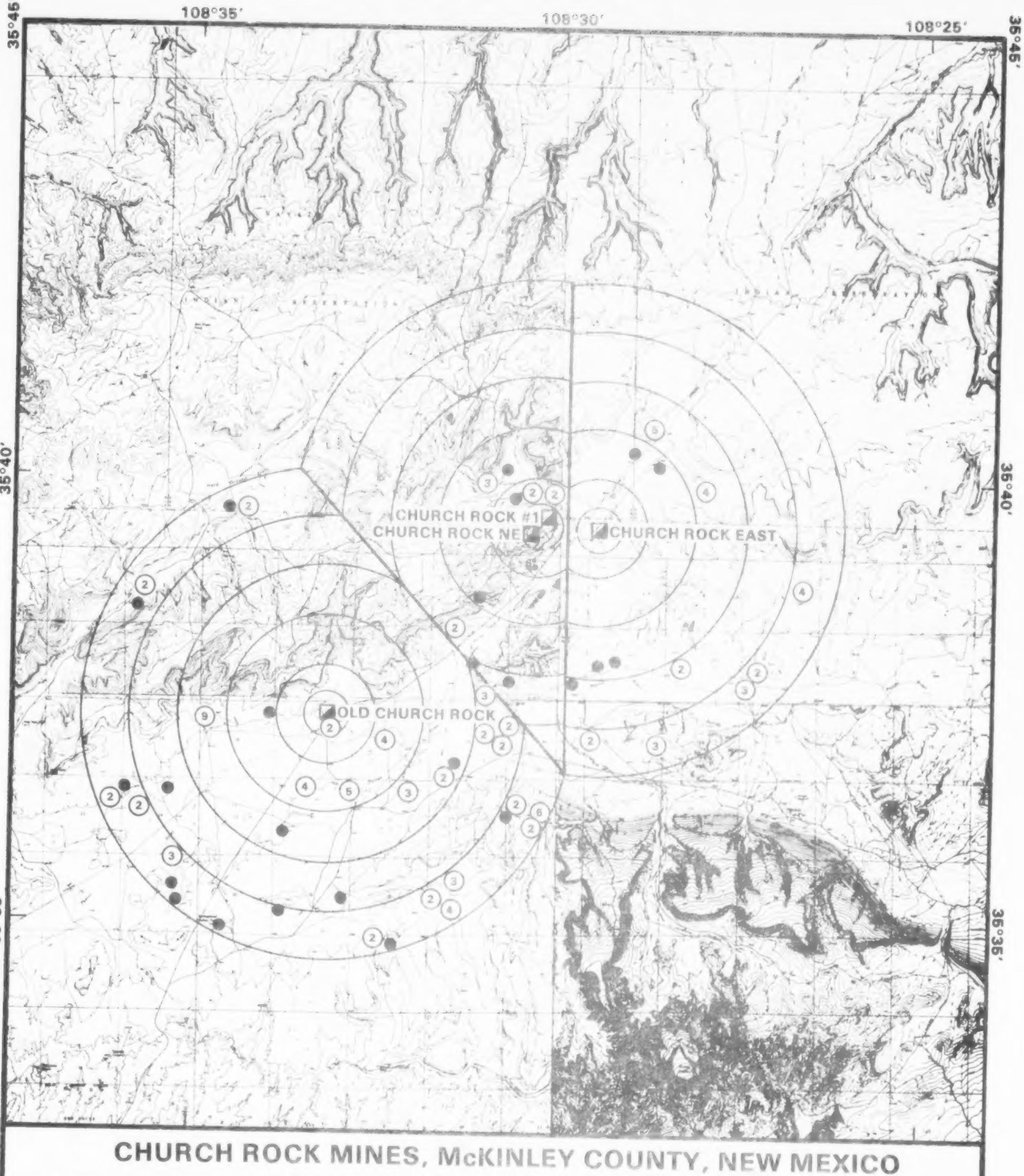
POPULATION DISTRIBUTION

MINE	0-1/2km	0-1 km	0-2 km	0-3 km	0-4 km	0-5 km
KERR-McGEE SEC. 30E	3	3	3	3	3	3
KERR-McGEE SEC. 30W	0	5	5	5	5	6
KERR-McGEE SEC. 19	0	0	0	4	4	4
KERR-McGEE SEC. 35	0	0	0	0	0	0
KERR-McGEE SEC. 36	0	0	0	0	0	0
HOMESTAKE SEC. 23	0	0	0	3	3	4
HOMESTAKE SEC. 25	0	0	0	0	0	0


0 1 2 3 4 MILES
0 1 2 3 4 5 6 KILOMETERS

LEGEND:

- ● SINGLE OCCUPIED DWELLING
- ② OCCUPIED DWELLING CLUSTER (NO. IS STRUCTURES)
- ◪ MINE SHAFT


108°35'
108°30'
108°25'
35°45'
35°40'
35°35'
CHURCH ROCK #1
CHURCH ROCK NE
CHURCH ROCK EAST
OLD CHURCH ROCK

CHURCH ROCK MINES, McKINLEY COUNTY, NEW MEXICO

ALL OCCUPIED DWELLINGS; MINE SHAFT LOCATIONS; POPULATION DISTRIBUTION

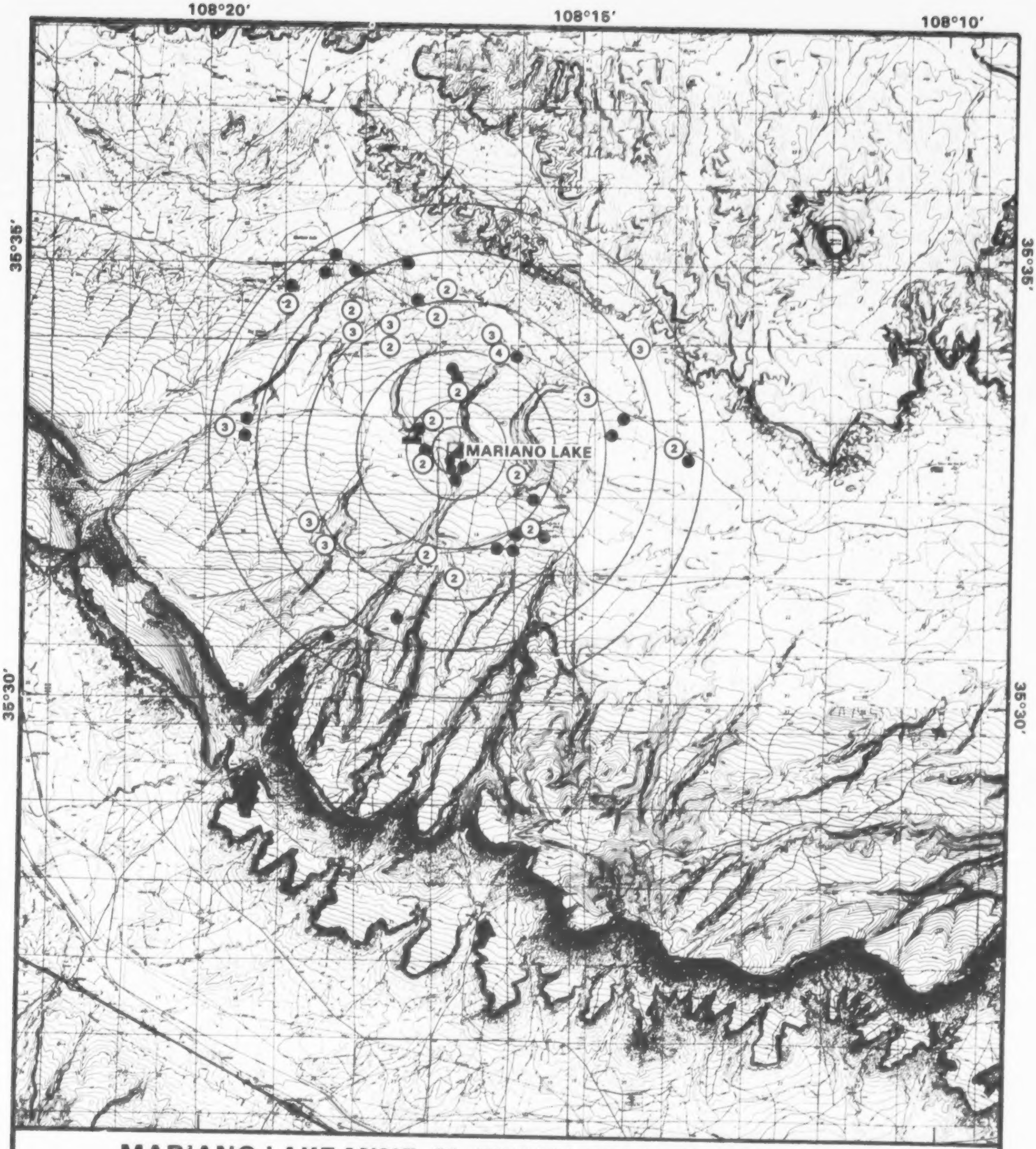
POPULATION DISTRIBUTION

MINE	0-1/2 km	0-1 km	0-2 km	0-3 km	0-4 km	0-5 km
OLD CHURCH ROCK	9	9	70	139	187	364
CHURCH ROCK NE	0	11	22	26	31	31
CHURCH ROCK #1	0	11	22	27	31	31
CHURCH ROCK EAST	0	0	9	67	70	131

0 1 2 3 4 MILES
0 1 2 3 4 5 6 KILOMETERS

LEGEND:

- ● SINGLE OCCUPIED DWELLING
- ② OCCUPIED DWELLING CLUSTER (NO. IS STRUCTURES)
- ◪ MINE SHAFT


108°20′
108°15′
108°10′
35°35′
35°30′
MARIANO LAKE

MARIANO LAKE MINE, McKINLEY COUNTY, NEW MEXICO

ALL OCCUPIED DWELLINGS; MINE SHAFT LOCATION; POPULATION DISTRIBUTION

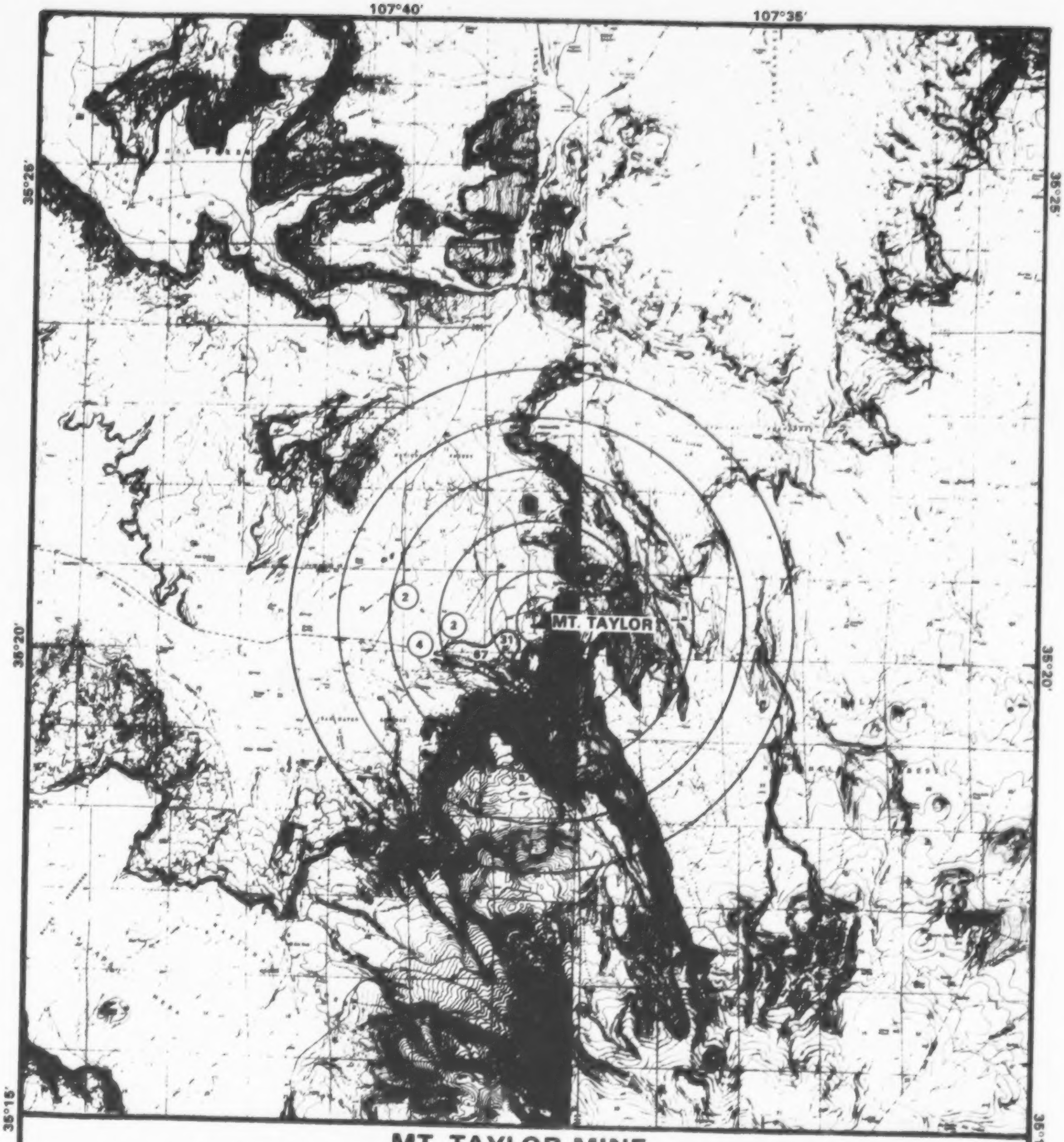
POPULATION DISTRIBUTION

MINE	0-1/2 km	0-1 km	0-2 km	0-3 km	0-4 km	0-5 km
MARIANO LAKE	13	44	75	196	274	352

0 1 2 3 4 MILES
0 1 2 3 4 5 6 KILOMETERS

LEGEND:

- ● SINGLE OCCUPIED DWELLING
- ② OCCUPIED DWELLING CLUSTER (NO. IS STRUCTURES)
- ◪ MINE SHAFT


107°40'
107°35'
35°25'
35°25'
35°20'
35°20'
35°15'
35°15'
2
2
4
31
67
MT. TAYLOR

MT. TAYLOR MINE
CIBOLA AND McKINLEY COUNTIES, NEW MEXICO

ALL OCCUPIED DWELLINGS; MINE SHAFT LOCATION; POPULATION DISTRIBUTION

POPULATION DISTRIBUTION

MINE	0-1/2 km	0-1 km	0-2 km	0-3 km	0-4 km	0-5 km
MT.TAYLOR	0	100	317	336	336	336

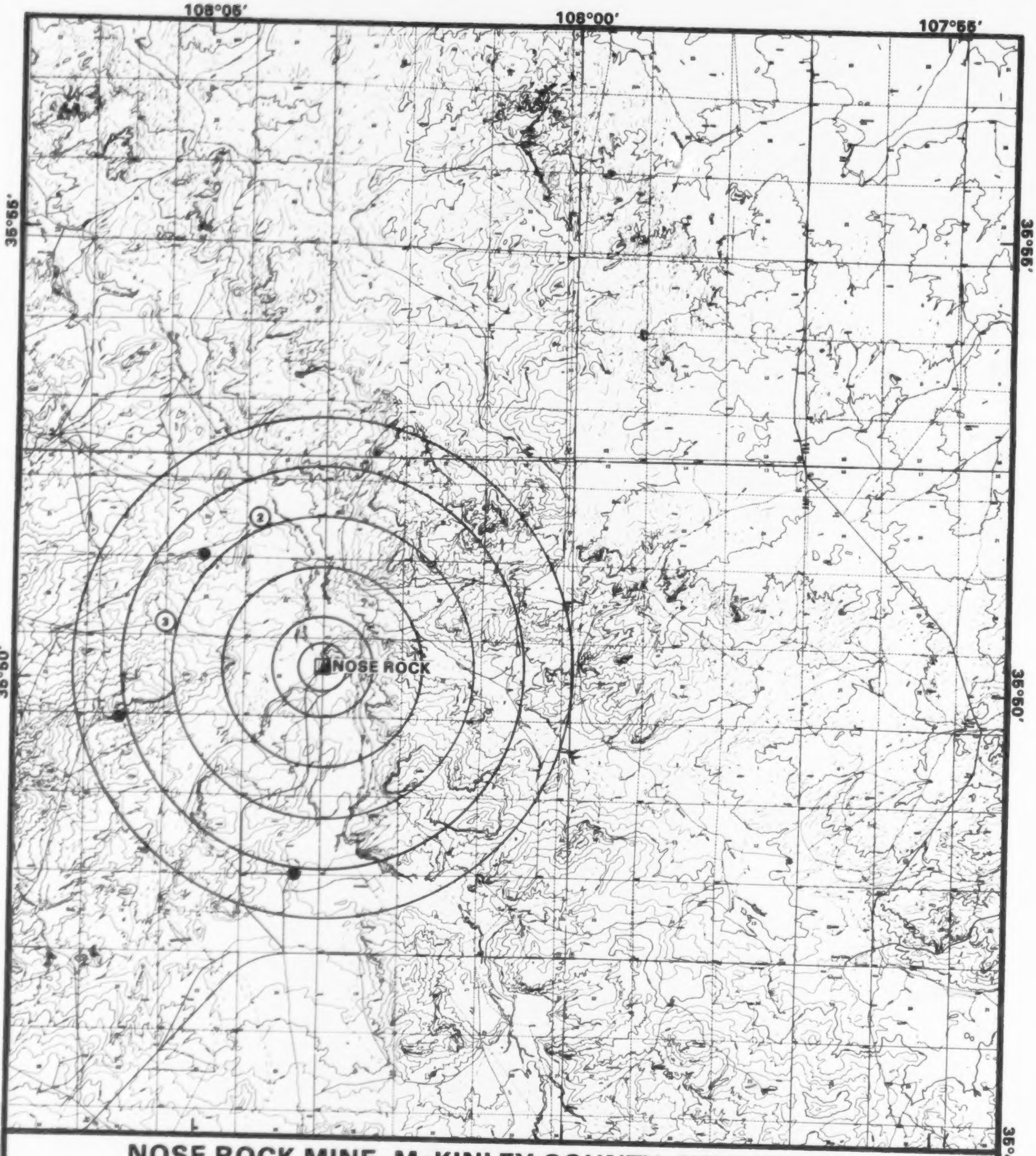
0 1 2 3 4 MILES
0 1 2 3 4 5 6 KILOMETERS

LEGEND:

● SINGLE OCCUPIED DWELLING

(2) OCCUPIED DWELLING CLUSTER (NO. IS STRUCTURES)

◪ MINE SHAFT


108°05'
108°00'
107°55'
35°55'
35°55'
35°50'
35°50'
35°45'
35°45'
NOSE ROCK
2
3

NOSE ROCK MINE, McKINLEY COUNTY, NEW MEXICO

ALL OCCUPIED DWELLINGS; MINE SHAFT LOCATION; POPULATION DISTRIBUTION

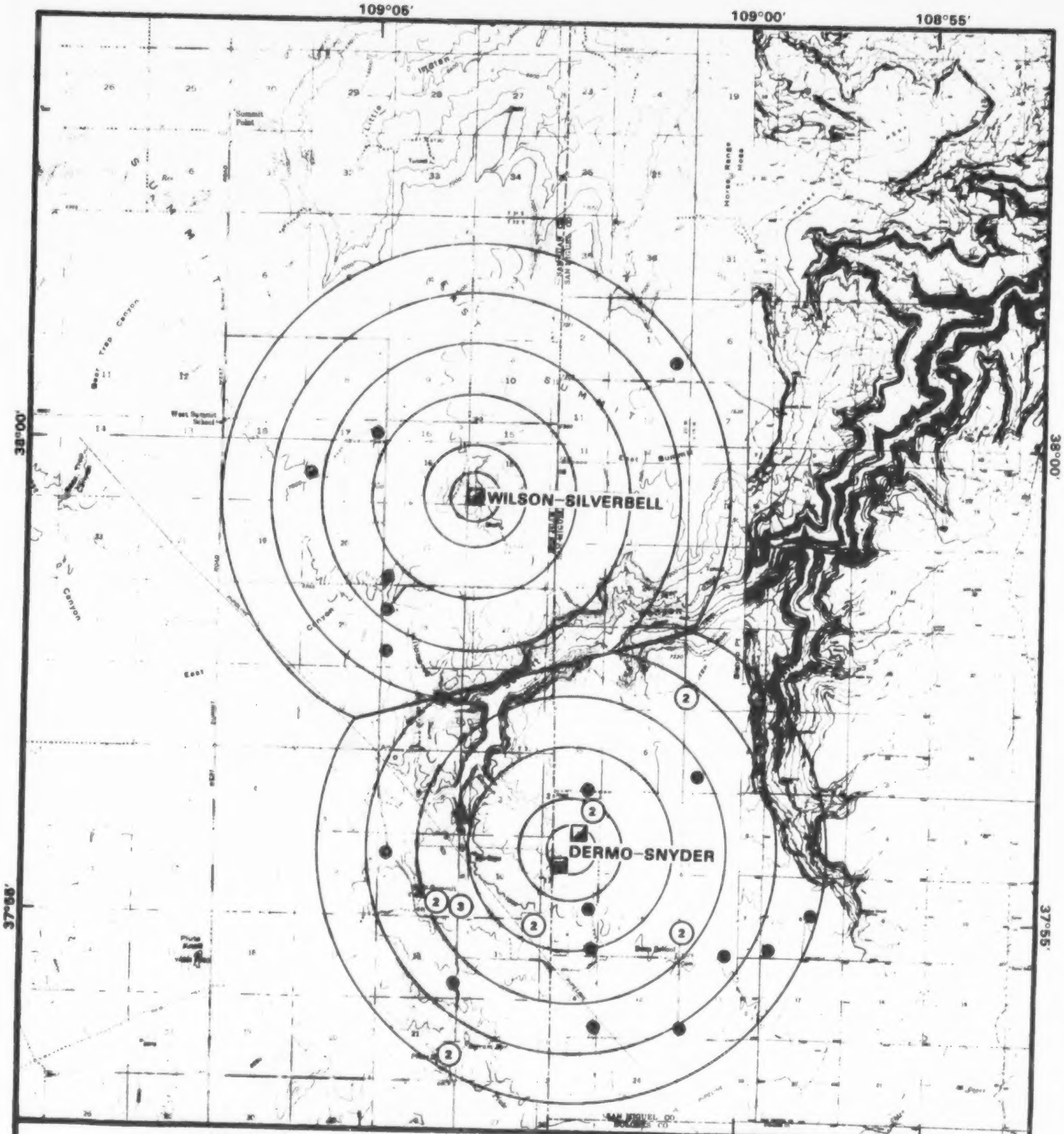
POPULATION DISTRIBUTION

MINE	0-1/2 km	0-1 km	0-2 km	0-3 km	0-4 km	0-5 km
NOSE ROCK	0	0	0	0	26	35

0 1 2 3 4 MILES
0 1 2 3 4 5 6 KILOMETERS

LEGEND:

- ● SINGLE OCCUPIED DWELLING
- ② OCCUPIED DWELLING CLUSTER (NO. IS STRUCTURES)
- ◩ MINE SHAFT


109°05'
109°00'
108°55'
38°00'
37°55'
WILSON–SILVERBELL
DERMO–SNYDER
SAN MIGUEL CO.
DOLORES CO.

DERMO–SNYDER/WILSON–SILVERBELL MINES
SAN JUAN COUNTY, UTAH, AND SAN MIGUEL COUNTY, COLORADO

ALL OCCUPIED DWELLINGS; MINE SHAFT LOCATIONS; POPULATION DISTRIBUTION

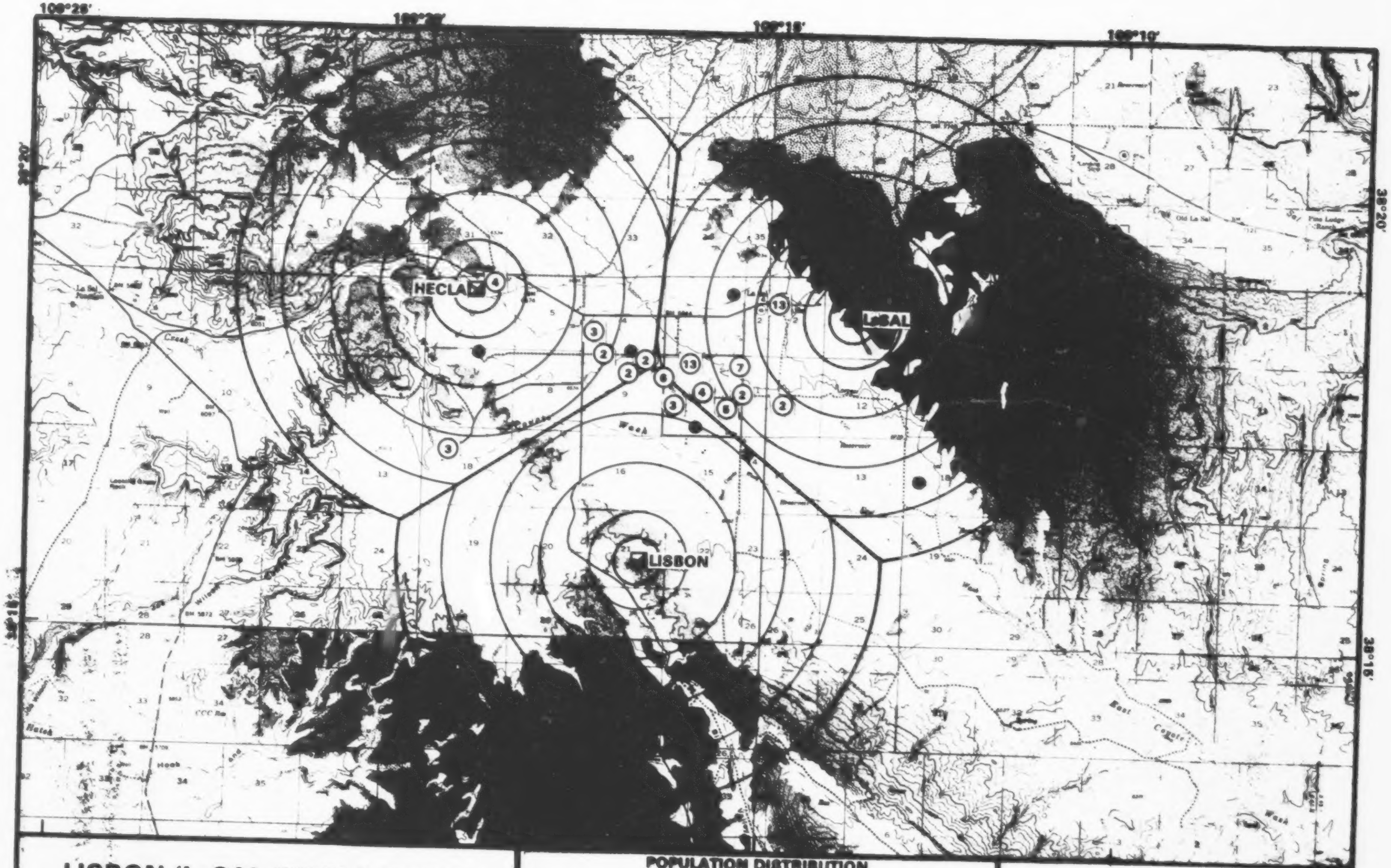
POPULATION DISTRIBUTION

MINE	0-1/2 km	0-1 km	0-2 km	0-3 km	0-4 km	0-5 km
DERMO–SNYDER	0	5	21	49	67	83
WILSON–SILVERBELL	0	0	0	12	20	23

0
1
2
3
4
MILES
0
1
2
3
4
5
6
KILOMETERS

LEGEND:

- ● SINGLE OCCUPIED DWELLING
- ② OCCUPIED DWELLING CLUSTER (NO. IS STRUCTURES)
- ◪ MINE SHAFT


109°25'
109°20'
109°15'
109°10'
38°20'
38°15'
HECLA
LaSAL
LISBON
Wash
Coyote
0
1
2
3
4
MILES
KILOMETERS

LISBON/LaSAL/HECLA MINES
SAN JUAN COUNTY, UTAH

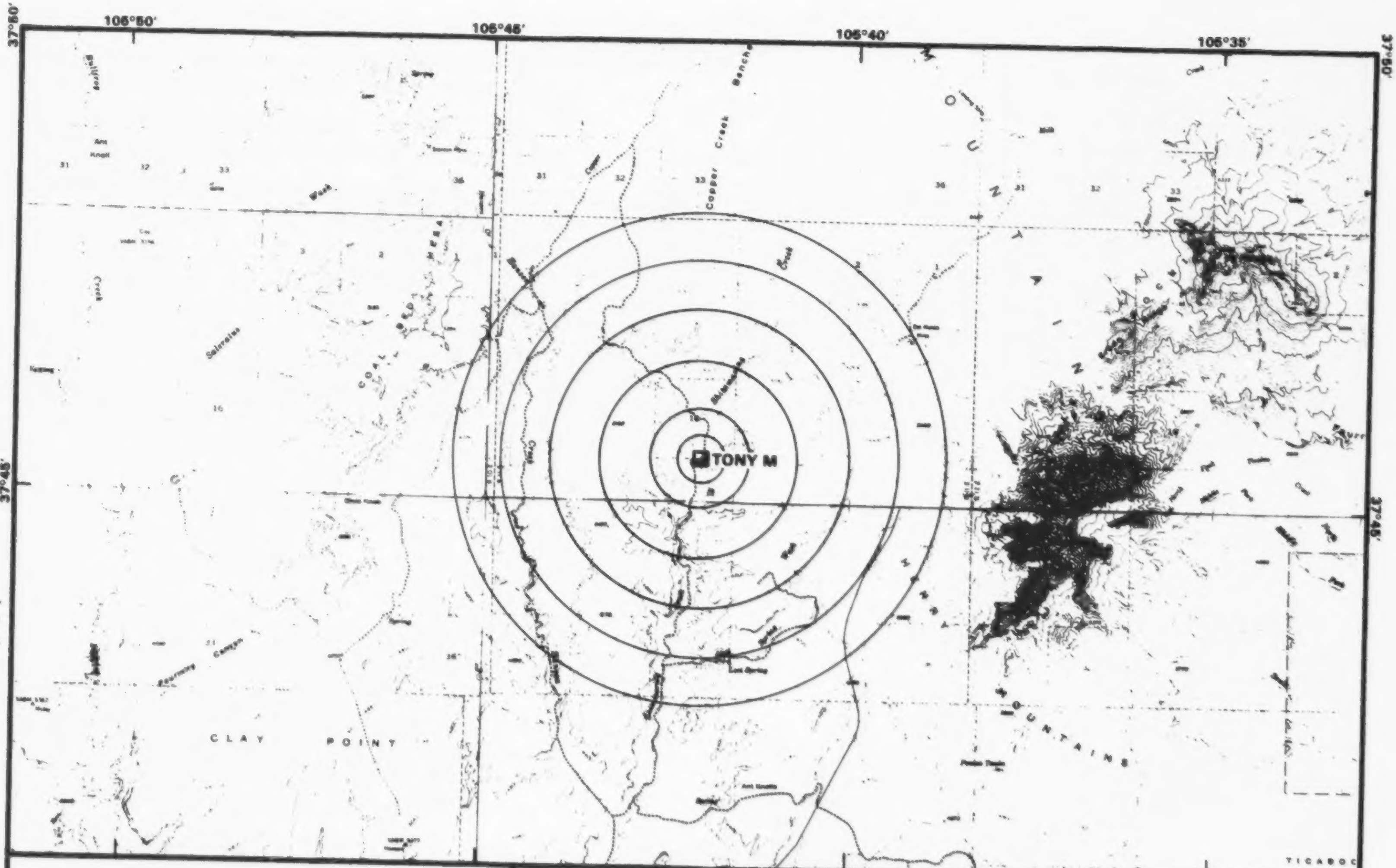
ALL OCCUPIED DWELLINGS; MINE SHAFT LOCATIONS; POPULATION DISTRIBUTION

POPULATION DISTRIBUTION

MINE	0-1/2 km	0-1 km	0-2 km	0-3 km	0-4 km	0-5 km
LISBON	0	0	0	4	44	44
LaSAL	0	0	53	101	194	194
HECLA	16	16	20	40	73	73

LEGEND:

- ● SINGLE OCCUPIED DWELLING
- ② OCCUPIED DWELLING CLUSTER (NO. IS STRUCTURES)
- ◩ MINE SHAFT


37°50'
105°50'
105°45'
105°40'
105°35'
37°50'
37°45'
37°45'
TONY M
Copper Creek Benche
Ant Knoll
COAL BED MESA
CLAY POINT
MOUNTAINS
TICABOO

TONY M MINE
GARFIELD COUNTY, UTAH

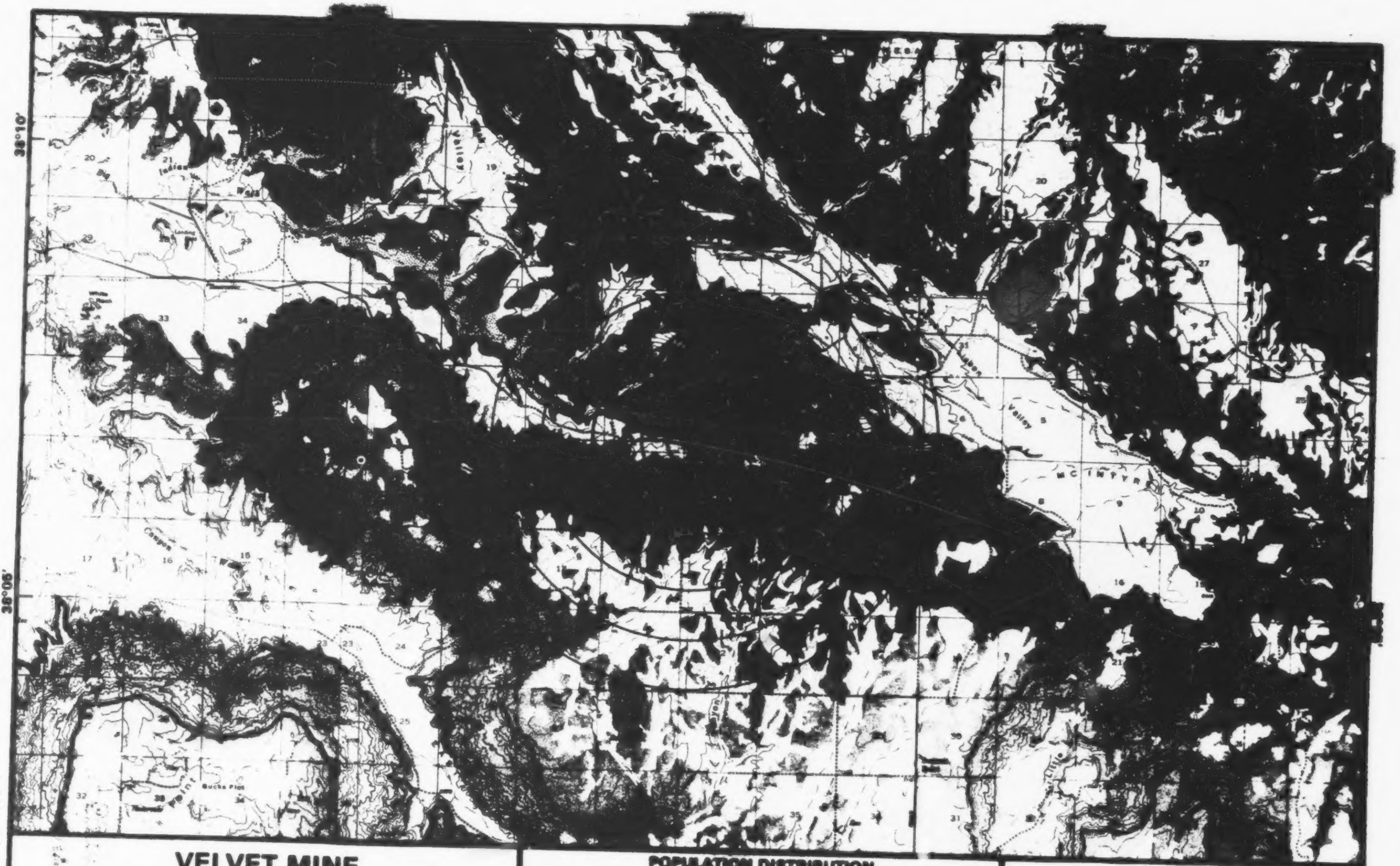
ALL OCCUPIED DWELLINGS; MINE SHAFT LOCATIONS; POPULATION DISTRIBUTION

POPULATION DISTRIBUTION

MINE	0-1/2 km	0-1 km	0-2 km	0-3 km	0-4 km	0-5 km
TONY M	0	0	0	0	0	0

0 1 2 3 4 MILES
0 1 2 3 4 5 6 KILOMETERS

LEGEND:
- ● SINGLE OCCUPIED DWELLING
- ② OCCUPIED DWELLING CLUSTER (NO. IS STRUCTURES)
- ◩ MINE SHAFT



VELVET MINE
SAN JUAN COUNTY, UTAH

ALL OCCUPIED DWELLINGS; MINE SHAFT LOCATION; POPULATION DISTRIBUTION

POPULATION DISTRIBUTION

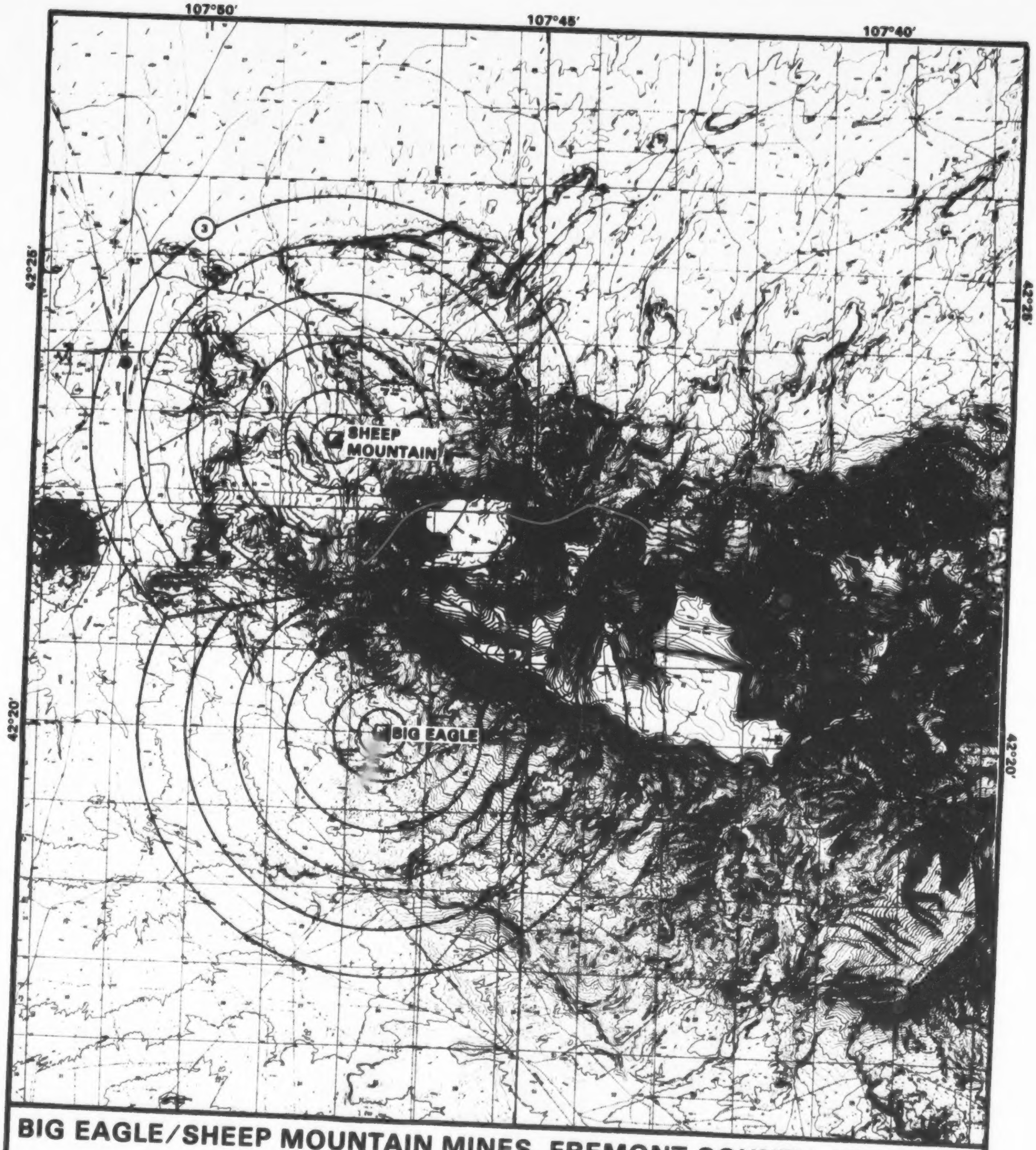
MINE	0-1/2 km	0-1 km	0-2 km	0-3 km	0-4 km	0-5 km
VELVET	0	0	0	0	0	0

0 1 2 3 4 MILES

0 1 2 3 4 5 6 KILOMETERS

LEGEND:

- ● SINGLE OCCUPIED DWELLING
- ② OCCUPIED DWELLING CLUSTER (NO. IS STRUCTURES)
- ◪ MINE SHAFT


107°50'
107°45'
107°40'
42°25'
42°20'
3
SHEEP MOUNTAIN
BIG EAGLE

BIG EAGLE/SHEEP MOUNTAIN MINES, FREMONT COUNTY, WYOMING

ALL OCCUPIED DWELLINGS; MINE SHAFT LOCATIONS; POPULATION DISTRIBUTION

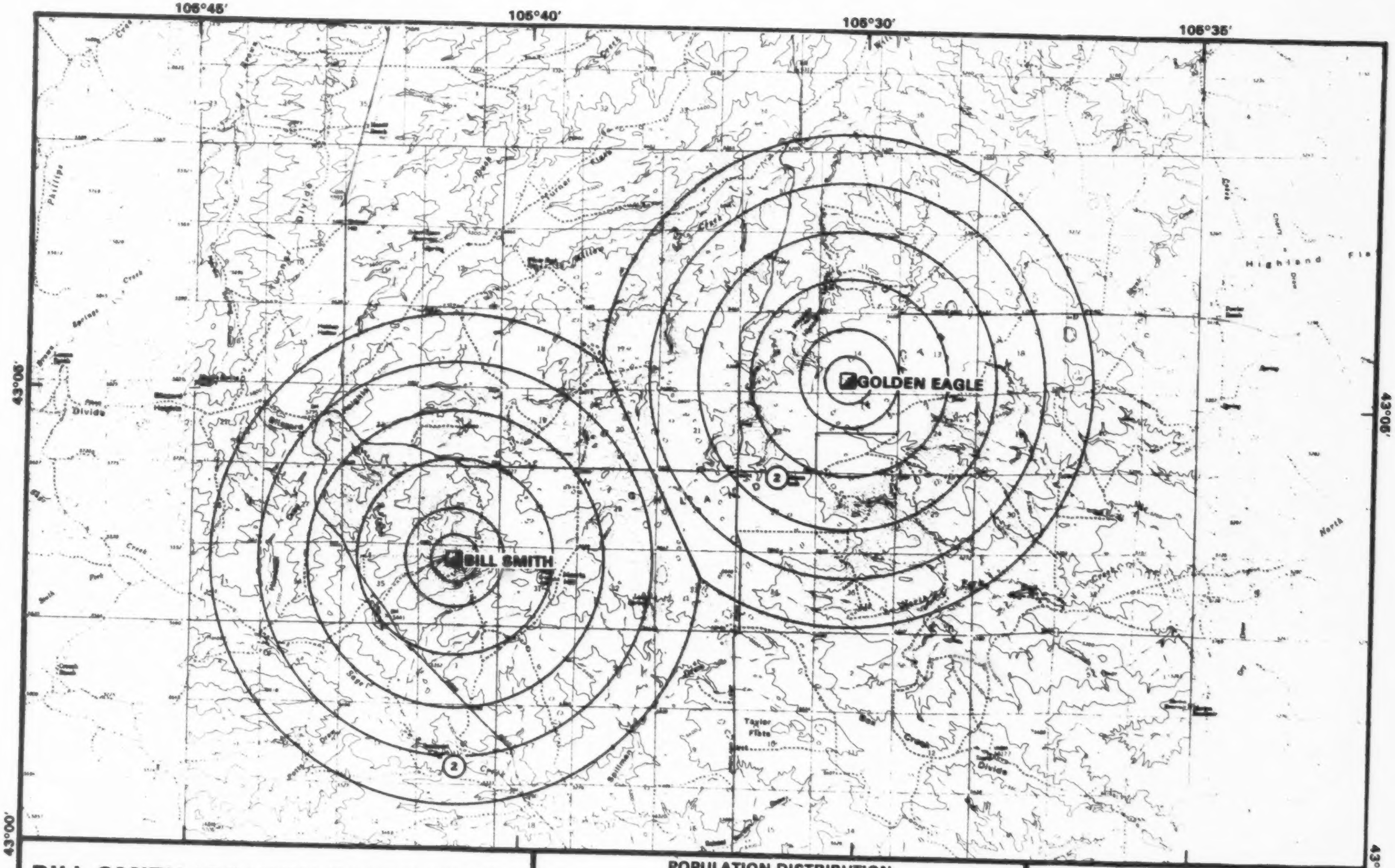
POPULATION DISTRIBUTION

MINE	0-1/2 km	0-1 km	0-2 km	0-3 km	0-4 km	0-5 km
BIG EAGLE	0	0	0	0	0	0
SHEEP MOUNTAIN	0	0	0	0	0	12

0 1 2 3 4 MILES
0 1 2 3 4 5 6 KILOMETERS

LEGEND:

- ● SINGLE OCCUPIED DWELLING
- ② OCCUPIED DWELLING CLUSTER (NO. IS STRUCTURES)
- ◪ MINE SHAFT


105°45'
105°40'
105°30'
105°35'
43°05'
43°00'
43°05'
43°00'
GOLDEN EAGLE
BILL SMITH
2
2
Highland Flat
Taylor Flats
Divide
Divide
North

BILL SMITH/GOLDEN EAGLE MINES CONVERSE COUNTY, WYOMING

ALL OCCUPIED DWELLINGS; MINE SHAFT LOCATIONS; POPULATION DISTRIBUTION

POPULATION DISTRIBUTION

MINE	0-1/2 km	0-1 km	0-2 km	0-3 km	0-4 km	0-5 km
BILL SMITH	0	0	0	0	0	6
GOLDEN EAGLE	0	0	0	6	6	6

0 1 2 3 4 MILES
0 1 2 3 4 5 6 KILOMETERS

LEGEND:
- ● SINGLE OCCUPIED DWELLING
- ② OCCUPIED DWELLING CLUSTER (NO. IS STRUCTURES)
- ◪ MINE SHAFT

REFERENCES

B184 Bloomster C. H., Jackson P. O., Dirks J. A., and Reis J. W., Radon Emissions from Underground Uranium Mines, Draft Report, Pacific Northwest Laboratory, 1984.

Bra81 Brown S. H. and Smith R. C., A Model for Determining the Overall Radon Release Rate and Annual Source Term for a Commercial In-Situ Leach Uranium Facility, Proceedings of International Conference on Radiation Hazards in Mining: Control Measurement, and Medical Aspects, Colorado School of Mines, Golden, Colorado, October 1981.

Brb84 Bruno G. A., Dirks J. A., Jackson P. O., and Young J. K., U.S. Uranium Mining Industry: Background Information on Economics and Emissions, Pacific Northwest Laboratory, PNL-5035 (UC-2, 11, 51) March 1984.

Bu83 Buhl T., Millard J., Baggett D., Brough T., and Trevathan S., Radon and Radon Progeny Concentration in New Mexico's Uranium Mining and Milling District, New Mexico Health and Environment Department, 1983.

DOE83 Department of Energy, Statistical Data of the Uranium Industry, GJO-100(83), Grand Junction, Colorado, January 1983.

Dra80 Droppo J. G., Jackson P. O., Nickola P. W., Perkins R. W., Sehmel G. A., Thomas C. W., Thomas V. W., and Wogman N. A., An Environmental Study of Active and Inactive Uranium Mines and Their Effluents, Part I, Task 3, EPA Contract Report 80-2, EPA, Office of Radiation Programs, Washington, D.C., August 1980.

Drb81 Droppo J. G. and Glissmeyer J. A., An Assessment of the Radon Concentrations in Air Caused by Emissions from Multiple Sources in a Uranium Mining and Milling Region. A Case Study of the Ambrosia Lake Region of New Mexico, Pacific Northwest Laboratory, PNL-4033, December 1981.

Drc84 Droppo J. G., Modeled Atmospheric Radon Concentrations from Uranium Mines, Draft Report, Pacific Northwest Laboratory, PNL-52-39, September 1984.

EPA79 Environmental Protection Agency, Radionuclide Impact Caused by Emissions of Radionuclides into Air in the United States, EPA 520/7-79-006, EPA, Office of Radiation Programs, Washington, D.C., August 1979.

REFERENCES--continued

EPA83a Environmental Protection Agency, Regulatory Impact Analysis of Final Environmental Standards for Uranium Mill Tailings at Active Sites, EPA 520/1-83-010, EPA, Office of Radiation Programs, Washington, D.C., September 1983.

EPA83b Environmental Protection Agency, Potential Health and Environmental Hazards of Uranium Mines Wastes, EPA 520/1-83-007, EPA, Office of Radiation Programs, Washington, D.C., June 1983.

EPA83c Environmental Protection Agency, Final Environmental Impact Statement for Standards for the Control of Byproduct Materials from Uranium Ore Processing (40 CFR 192), Volume II, page A.2-33, EPA 520/1-83-008-2, EPA, Office of Radiation Programs, Washington, D.C., September 1983.

EPA83d Environmental Protection Agency, Background Information Document--Proposed Standards for Radionuclide Draft Report, EPA 520/1-83-001, EPA Office of Radiation Programs, Washington, D.C., March 1983.

Fra81 Franklin J. C., Control of Radiation Hazards in Underground Mines, Bureau of Mines, Proceedings of International Conference on Radiation Hazards in Mining: Control Measurement, and Medical Aspects, Colorado School of Mines, Golden, Colorado, October 1981.

Frb81 Franklin J. C. and Weverstad K. D., Radiation Hazards in Backfilling with Classified Uranium Mill Tailings, Proceedings of the Fifth Annual Uranium Seminar, Albuquerque, New Mexico, September 20-23, 1981.

Frc83 Written communication between J. C. Franklin of the Bureau of Mines and W. J. Shelley of the Kerr-McGee Corporation, May 1983.

He75 Heffter J. L., Taylor A. D., and Ferber G. J., A Regional-Continental Scale Transport, Diffusion, and Deposition Model, NOAA Tech. Memo, ERL/ARL-50, 1975.

Ho84 Hopke P. K., Leong K. H., and Stukel J. J., Mechanisms for the Removal of Radon from Waste Gas Streams, EPA Cooperative Agreement CR 806819, UILU-ENG 84-0106, Advanced Environmental Control Technology Research Center, 3230 Newmark Civil Engineering Laboratory, 208 North Romine Street, Urbana, Illinois 61801, March 1984.

Ja80 Jackson P. O., Glissmeyer J. A., Enderlin W. I., Schwendiman L. C., Wogman N. A., and Perkins R. W., An Investigation of Radon-222 Emissions from Underground Uranium Mines--Progress Report 2, Pacific Northwest Laboratory, Richland, Washington, February 1980.

Ko80 Kown B. T., VanderMast V. C., and Ludwig K. L., Technical Assessment of Radon-222 Control Technology for Underground Uranium Mines, ORP/TAD-80-7, Contract No. 68-02-2616, EPA, Office of Radiation Programs, Washington, D.C., April 1980.

NRC80 Nuclear Regulatory Commission, Final Generic Environmental Impact Statement on Uranium Milling, NUREG-0706, Office of Nuclear Material Safety and Safeguards, NRC, Washington, D.C., September 1980.

Th81 Thomas W. V., Musulin C. S., and Franklin J. C., Bulkheading Effects on Radon Release from the Twilight Uranium Mine, PNL-3693 (UC-11). Prepared for EPA under a Related Services Agreement with DOE, Pacific Northwest Laboratory, Richland, Washington, June 1981.

Tr79 Travis C. C., Watson A. P., McDowell-Boyer L. M., Cotter S. J., Randolph M. L., and Fields D. E., A Radiological Assessment of Radon-222 Released from Uranium Mills and Other Natural and Technologically Enhanced Sources, ORNL/NUREG-55, ORNL, Oak Ridge, Tennessee, 1979.

Chapter 6: PHOSPHATE INDUSTRY FACILITIES

6.1 Phosphate Rock Processing Plants

6.1.1 General Description

Phosphate rock is the starting material for the production of all phosphate products. Mining of phosphate rock is the fifth largest mining industry in the United States in terms of quantity of material mined (DM68). Phosphate rock mines of significant commercial importance are located in Florida, North Carolina, Tennessee, Idaho, Wyoming, Utah, and Montana (Figure 6.1-1).

The U.S. production of phosphate rock was estimated to be 57.9 million metric tons in 1978 with production increasing an average of about 5 percent per year (EPA79). The industry consists of 20 firms which are currently mining phosphate rock at 31 locations. Another five mines are expected to be operational by 1983, and four others have been planned with indefinite start-up dates. Most firms have mining operations and rock processing plants at the same location, while a few companies mine in several areas and ship the rock to a central processing plant. Table 6.1-1 shows the phosphate rock producing companies, plant locations, 1977 production, and percent of U.S. market.

The southeastern U.S. is the center of the domestic phosphate rock industry, with Florida, North Carolina, and Tennessee having over 90 percent of the domestic rock capacity. Florida, with approximately 78 percent of 1978 domestic capacity, dominates the U.S. industry and is the world's largest phosphate rock producing area. Most of these plants are located around Polk and Hillsborough counties in Central Florida, with expansion taking place in Hardee and Manatee counties. Hamilton County, located in North Florida, is another phosphate rock producing area.

Tennessee's phosphate rock industry, located in the middle of the State, has declined in importance over the last several years and is now the least important rock producing area in the country. The Tennessee Valley Authority and two private corporations have discontinued mining in Tennessee, and no new plant expansion is planned.

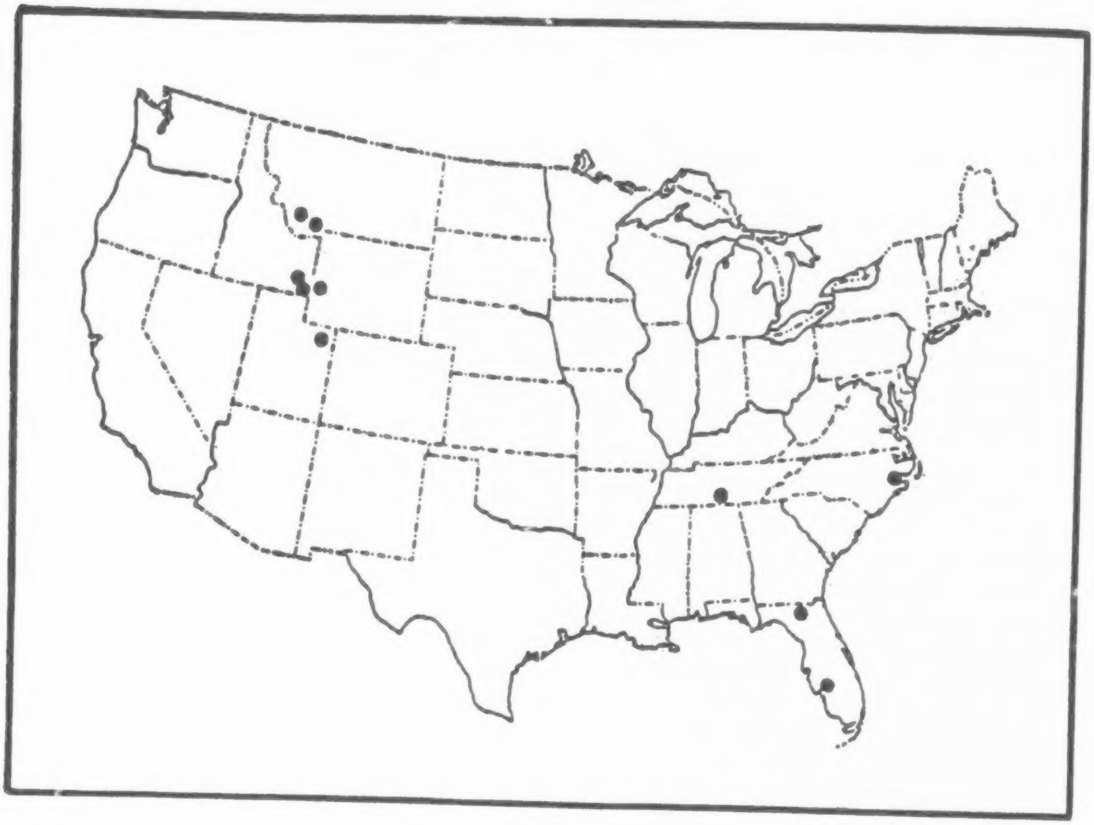


Figure 6.1-1. Geographical location of phosphate rock operations.

Table 6.1-1. Phosphate rock producers and capabilities (EPA79)

Company and location	1977 production (Metric tons) (10^3)	Percent of total
International Minerals and Chemicals Bonnie, Florida Kingsford, Florida Noralyn, Florida	11,340	20.5
Agrico Chemical Co. (Williams) Pierce, Florida Ft. Green, Florida	8,618	15.6
Occidental Agricultural Chemicals White Springs, Florida	2,722	4.9
Mobile Chemical Nichols, Florida Fort Meade, Florida	4,264	7.7
Brewster Phosphate Brewster, Florida Bradley, Florida	3,175	5.7
U.S. Steel-Agri-Chem, Inc. Ft. Meade, Florida	1,814	3.3
Gardinier Ft. Meade, Florida	1,966	3.6
Swift Chemical Bartow, Florida	2,903	5.3
W.R. Grace & Company Hookers Pr., Florida Bonnie Lake, Florida Manatte Co., Florida	4,808	8.7
Borden Chemical Company Teneroc, Florida Big Four, Florida	907	1.6
T-A Minerals Polk City, Florida	454	0.8

Table 6.1-1. Phosphate rock producers and capabilities (EPA79) (Continued)

Company and location	1977 production (Metric tons) (10^3)	Percent of total
Beker Industries Dry Valley, Idaho	1,089	2.0
J.R. Simplot Ft. Hall, Idaho	1,814	3.3
Cominco-American Garrison, Montana	249	0.5
George Relyea Garrison, Montana	91	0.2
Texasgulf Aurora, North Carolina	4,536	8.2
Stauffer Chemical Company Mt. Pleasant, Tennessee Vernal, Utah Wooley Valley, Utah	1,950	3.5
Hooker Chemical Company Columbia, Tennessee	454	0.8
Presnell Phosphate Columbia, Tennessee	454	0.8
Monsanto Industrial Chemical Co. Columbia, Tennessee Henry, Idaho	1,814	3.3

Summary by Region

Location	Percent of total U.S.
Florida	78.3
North Carolina	7.8
Tennessee	4.1
Western States	9.8

North Carolina possesses a rich phosphate rock deposit in Beaufort County along the Pamlico River. Texasgulf, the only company currently exploiting this resource, recently expanded plant capacity by 43 percent and has plans for further expansion. Another company has announced plans for a large operation in Washington, North Carolina.

The western U.S. phosphate rock industry is located in eastern Idaho, northern Utah, western Wyoming, and southern Montana. This area accounts for almost six million metric tons per year of the U.S. capacity, or about 10 percent. Six companies currently operate seven mines and six processing plants.

The U.S. industry is relatively concentrated as the 10 largest producers control about 84 percent of the capacity. The two largest companies control over 34 percent. In the Florida region, two firms have nearly 44 percent of the State's capacity, while the five largest companies control over 70 percent (EPA79).

The principal ingredient of the phosphate rock that is of economic interest is tricalcium phosphate, $Ca_3(PO_4)_2$. However, phosphate rock also contains appreciable quantities of uranium and its decay products. The uranium concentration of phosphate rock ranges from 20 to 200 ppm which is 10 to 100 times higher than the typical uranium concentration in rocks and soils (2 ppm). The radionuclides of significance which are present in phosphate rock are: uranium-238, uranium-234, thorium-230, radium-226, radon-222, lead-210, and polonium-210. Because phosphate rock contains elevated concentrations of these radionuclides, handling and processing the rock can release radionuclides into the air either as dust particles, or in the case of radon-222, as a gas.

6.1.2 Process Description

After phosphate rock has been mined and beneficiated, it is usually dried and ground to a uniform particle size to facilitate processing. The drying and grinding operations produce significant quantities of particulate material (phosphate rock dust).

Phosphate rock is dried in direct-fired rotary or fluidized-bed dryers. The rock contains 10-15 percent moisture as it is fed to the dryer and is discharged when the moisture content reaches 1-3 percent. Dryer capacities range from 5 to 350 tons per hour (tph), with 200 tph a representative average.

Crushing and grinding are widely employed in the processing of phosphate rock. Operations range in scope from jaw crushers which reduce 12-inch hard rock to fine pulverizing mills which produce a product the consistency of talcum powder. Crushing is employed in some locations in the western field; however, these operations are used for less than 12 percent of the rock mined in the U.S. Fine pulverizing mills or grinders are used by all manufacturers to produce fertilizer. Roller or ball mills are normally used to process from 15 to 260 tph.

Some phosphate rock must be calcined before it can be processed. The need for calcining is determined primarily by the quantity of organic materials in the beneficiated rock. Since Florida rock is relatively free of organics, it usually is not calcined. Most calcining is done in fluidized-bed units, but rotary calciners are also used. The rock is heated to 1400°-1600° F in the calciner to remove unwanted hydrocarbons. Calciners range in capacity from 20 to 70 tph; a representative average is about 50 tph (EPA79).

6.1.3 Control Technology (TRW82)

At phosphate rock plants, the normal sequence of operation is: mining, beneficiation, conveying of wet rock to and from storage, drying or calcining, conveying and storage of dry rock, grinding, and conveying and storage of ground rock.

Over 98 percent of the phosphate rock produced in the United States is mined from ground where the moisture content is high enough to preclude particulate emissions during extraction of the ore. In the relatively small amount of mining performed in areas where ground moisture content is not sufficient to prevent emissions, such as the hard rock areas of Utah and Wyoming, some particulates are generated during blasting and handling of the overburden and ore body. These emissions are minimized by wetting the active mining area with water from tank trucks.

Beneficiation is performed in a water slurry. Since the rock is wet, it does not become airborne and presents no particulate problem. Mined rock is normally moved by conveyor belts. Some are open, others closed for weather protection. In all except the relatively small plants in the hard rock areas of Utah and Wyoming, the high moisture content of the rock prevents emission of particulates. Weather-protected conveyors also offer some emission control in arid or windy locations.

Particulates from conveying and storage of ground rock are due primarily to fugitive emissions. Conveying and storage of ground rock usually takes place in totally enclosed systems, where proper maintenance will minimize fugitive losses.

Particulate emissions from dryers, calciners, and grinders could be reduced by applying particulate control equipment to "non-fugitive" emission sources.

Controlled emission levels from dryers and calciners can vary considerably from unit to unit, even with the same control device, due primarily to the effects of feed rock characteristics. Industrial representatives have indicated that feed rock characteristics greatly outweigh the effects of dryer or calciner unit types. Several feed rock characteristics can affect the emission levels and particle size distribution of the exhaust gas streams. Surface properties affect emission levels; rough or pitted surfaces can have greater clay adhesion, resulting in higher emission levels and smaller average particle size.

During beneficiation, the least-washed rock will have more fines, higher emission levels, and smaller average particle size. The residence time during which the rock is dried or calcined may also affect emission levels. Although increasing the residence time may lower particulate concentration per volume of exhaust gas, the total weight of particulate emission per weight of feed rock will increase. Other feed rock characteristics can also cause fluctuations in the particulate emission levels.

Coarse pebble rock from Florida is beneficiated the least and has the longest residence time in the dryer of all Eastern rock. Along with other properties, including hardness and clay adhesion, these properties cause coarse pebble rock to produce the most adverse, or worst-case, control levels for Eastern operations. However, unbeneficiated Western rock has a slightly smaller average particle size than Eastern rock and represents the most adverse of all feed rock control situations.

Dryer and Calciner Controls

Phosphate rock calciners and dryers have similar emission characteristics. Scrubbers are the most common control device used in the operation of phosphate rock dryers and calciners. Probably the most important design parameters for scrubbers are the amount of scrubber water used per unit volume of gas treated (liquid-to-gas ratio) and the intimacy of contact between the liquid and gas phases. The latter parameter is generally related to the pressure drop across the scrubber. Because of the similarities in emissions from dryers and calciners, scrubbers can attain similar reduction efficiencies; up to greater than 99.0 percent for high-energy venturi scrubbers.

Electrostatic precipitators (ESP) can be an economical control technique. Plate (electrode) voltage and the ratio of plate area to the volume of gas to be treated are the most important design parameters of an ESP. Particle resistivity and the ease of cleaning collected dust from the plates also affect ESP performance. Electrostatic precipitation is sometimes an economically attractive control technique in cases where fine dust particles predominate. Removing fine particles with a venturi scrubber requires relatively large power inputs (high pressure drops) to achieve the necessary efficiency. If power cost savings effected by the ESP exceed the increased capital charges, this system can be more economical than the venturi scrubber.

Two phosphate rock dryers now use electrostatic precipitators. One has a conventional dry ESP to control emissions from two rotary dryers. The precipitator was designed for 95 percent efficiency, but typically operates at 93 percent. The other uses a wet ESP to control emissions from two dryers operated in parallel, one a rotary design and the other a fluid bed. The ESP was designed for an efficiency of 90 percent, but is probably operating at a higher efficiency because the gas flow rate is about 60 percent of design capacity. With variation in plate voltage and plate area, ESP's can be designed to achieve reduction efficiencies up to greater than 99 percent. A calciner at one existing operation has a two-stage, dry ESP which operates with an indicated overall efficiency of 99.8 percent.

No fabric filters are known to be in use for phosphate rock dryer and calciner emission control. Many industry members believe that moisture condensation would be a major problem because water droplets could mix with the clay-like dust mat formed on the fabric media and cause a mud cake. Were this condition to occur, it would "blind" the bags. Furthermore, since the dust usually has no economical value, dry recovery for reprocessing is not an attractive incentive to operators. High exhaust gas temperatures associated with calciners are also commonly cited as a major difficulty expected with this type control device. However, manufacturers of these devices believe fabric filters can be effective for this application. They state that successful operation of fabric filters are common in more difficult operations, such as asphalt plants, cement plants, fertilizer dryers, and the clay industry. Under proper operating conditions, fabric filters generally exceed 99 percent efficiency.

Grinder Controls

Dried and calcined rock is ground before it is used for the manufacture of fertilizers. The grinding or milling circuit operates under slightly negative pressure to prevent the escape of gases containing ground rock dust. The system is not airtight; hence, the air that is drawn into the system must be vented. This vent stream usually discharges through a fabric filter or, sometimes, a wet scrubber. Electrostatic precipitators are not used for this operation at existing facilities.

Fabric filters are normally used to control emissions from grinders, probably because the dust collected by a fabric filter can be added directly to the product and thereby increase yields. Also, the low moisture content of 5 percent or less and low temperatures make fabric filtration technically and economically feasible. A well maintained and operated baghouse routinely controls particulate emissions to levels greater than 99 percent.

In some plants higher moisture content of the ground rock dust causes difficulty. At these plants, wet collectors are usually chosen for control. These devices can typically control emissions from 90 to

98 percent depending on the pressure drop. There has been a recent move toward wet grinding of rock for the manufacture of wet-process phosphoric acid (WPPA). The rock is ground in a water slurry, then added to the WPPA reaction tanks without drying. This offers the advantages of lower fuel costs and ability to meet more stringent particulate emission regulations. Two companies are now using the wet grinding process.

6.1.4 Radionuclide Emission Measurements

Phosphate rock dust is a source of particulate radioactivity in the atmosphere because the dust particles have approximately the same specific activity (pCi/g) as in the phosphate rock. Very limited data are available for actual field measurements of radioactivity in dryer/grinder air emissions. Measurements made by EPA (EPA78) are summarized in Table 6.1-2.

Table 6.1-2. Radionuclide stack emissions measured at phosphate rock dryers (EPA78)

Parameter	Dryer 1	Dryers 3 and 4
Total particulates (g/y)	2.2E+7	5.0E+7
Operating time (hr/y)	4114	4338
Stack emissions (Ci/y)		
Uranium-234	7.0E-4	2.6E-3
Uranium-235	3.0E-5	2.4E-4
Uranium-238	6.6E-4	2.7E-3
Thorium-227	5.0E-5	2.0E-4
Thorium-228	1.4E-4	2.3E-4
Thorium-230	9.7E-5	2.5E-3
Thorium-232	3.0E-5	8.0E-5
Radium-226	9.3E-4	2.9E-3

More recently, in 1983 and 1984, EPA measured the radionuclide emissions from phosphate-rock calciners. Because calciners operate at a higher temperature than dryers, they have the potential for volatilizing lead-210 and polonium-210. Information on the measurements made at calciners at elemental phosphorus plants is presented in Section 6.3. (Note: phosphate rock processing at elemental phosphorus plants has been analyzed separately from other phosphate rock processing facilities.) An analysis of the results of measurements at calciners at wet process phosphoric acid plants has not yet been completed and the following sections do not include an assessment of the health impact of radionuclide emissions from these calciners.

6.1.5 Reference Plant

Table 6.1-3 describes the parameters of a reference phosphate rock drying and grinding plant which are used to estimate the radioactive emissions to the atmosphere and the resulting health impacts. The radioactive emissions from the reference plant are listed in Table 6.1-4. These emissions are representative of dryers with low energy scrubbers which releases 130 grams of particulates per MT of rock processed and of grinders with medium energy scrubbers which release 25 grams of particulates per MT of rock processed.

Table 6.1-3. Reference phosphate rock drying and grinding plant

Parameter	Dryers	Grinders
Number of units[a]	3	4
Phosphate rock processing rate (MT/y)	2.7E+6	1.2E+6
Operating factor (hr/y)	6570	6460
Uranium-238 content of phosphate rock (pCi/g)[b]	40	40
Stack parameters		
Height (meters)	20	20
Diameter (meters)	2	2
Exit gas velocity (m/s)	10	10
Exit gas temperature (°C)	60°	60°
Type of control system	Low energy scrubber	Medium energy scrubber
Particulate emission rate (g/MT)	130 (0.26)[c]	25 (0.05)[c]

[a] Dryer units process 145 MT/hr; grinder units process 45 MT/hr.

[b] Uranium-238 is assumed to be in equilibrium with its daughter products.

[c] Values in lb/ton.

Table 6.1-4. Radionuclide emissions from the reference phosphate rock drying and grinding plant

Radionuclide	Emissions (Ci/y)	
	Dryers	Grinders
Uranium-238	1.4E-2	1.0E-3
Uranium-234	1.4E-2	1.0E-3
Thorium-230	1.4E-2	1.0E-3
Radium-226	1.4E-2	1.0E-3
Lead-210	1.4E-2	1.0E-3
Polonium-210	1.4E-2	1.0E-3

6.1.6 Health Impact Assessment of Reference Plant

The estimated annual radiation doses from radionuclide emissions from the reference phosphate rock drying and grinding plant are listed in Table 6.1-5. These estimates are for a model site in central Florida with a regional population of 1.4E+6. The nearby individuals are located 750 meters from the plant.

Table 6.1-6 presents estimates of the lifetime risk to nearby individuals and the number of fatal cancers per year of operation from these doses.

The lifetime risk to nearby individuals is estimated to be about 1E-5 and the number of fatal cancers per year of operation is estimated to be 1E-3. These risks result primarily from doses to the lung from inhalation of radioactive particulates released from drying operations.

6.1.7 Existing Emission Standards and Air Pollution Controls

No Federal or State regulations currently exist that limit radionuclide emissions from phosphate drying, calcining, and grinding operations. Particulate emissions from these sources are limited by New Source Performance Standards (NSPS) which apply to facilities constructed after September 1979, or State Implementation Plans (SIPs) which cover sources operating prior to September 1979.

NSPS limits for phosphate rock processing are 30 g/MT for dryers, 115 g/MT for calciners handling unbeneficiated rock or a blend of beneficiated and unbeneficiated rock, 55 g/MT for calciners handling beneficiated rock, and 6 g/MT for grinders.

SIP limits for phosphate rock operations are less stringent than NSPS limits. Florida, where approximately 80 percent of the industry is located, has established the most stringent SIP requirements, limiting emissions from 30, 100, and 500 tons/hour processing sources to 30, 36, and 47 lb/hour, respectively. SIP limits in the other six States where commercial facilities are located are 40, 51, and 79 lb/hour for processing rates of 30, 100, and 500 tons/hour.

6.1.8 Alternative Control Technology

The annualized costs and risk reductions achieved by adding alternative controls to the reference phosphate rock drying and grinding plant are shown in Table 6.1-7. Two alternative levels of control are evaluated for dryers:

1. Reduction of the particulate emissions to 50 g/MT through the use of medium energy venturi scrubbers or ESP's.

2. Reduction of the particulate emissions to 30 g/MT (level of New Source Performance Standards--NSPS) through the use of high energy venturi scrubbers or high energy ESP's.

For grinders, only one alternative level of control is evaluated; the reduction of the particulate emissions to 6 g/MT (level of NSPS) through the use of fabric filters or high energy venturi scrubbers.

Table 6.1-5. Annual radiation dose from radioactive particulate emissions from the reference phosphate rock drying and grinding plant

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Lung	7.2	6.0E+1
Endosteum	1.5E+1	1.1E+2
Red marrow	1.3	9.2
Kidney	1.0	6.8

Table 6.1-6. Fatal cancer risks due to radioactive emissions from the reference phosphate rock drying and grinding plant

Source	Lifetime risk to nearby individuals	Regional population (Fatal cancers/y of operation)
Dryers	1E-5	1E-3
Grinders	1E-6	1E-4
Total	1E-5	1E-3

Table 6.1-7. Annualized cost and risk reductions of alternative controls for the reference phosphate rock drying and grinding plant(a)

Process	Control option(b)	Emission rate (g/MT)	Total annual cost(c) ($1,000)	Fatal cancer risks: Risk to nearby individuals	Fatal cancer risks: Population (cancers/y of operation)	Cost/fatal cancer avoided (in millions)
Dryers(b)	Existing	130	-	1E-5	1E-3	-
	B-1	50	861	4E-6	4E-4	1440
	B-2	50	1770	4E-6	4E-4	2950
	A-1	30(d)	1000	2E-6	2E-4	1250
	A-2	30	2320	2E-6	2E-4	2900
Grinders	Existing	25	-	1E-6	1E-4	-
	A-1	6(d)	124	2E-7	2E-5	1550
	A-2	6	4	2E-7	2E-5	50

(a) TRW82.

(b) For dryers:
B-1 = venturi scrubber (15" W.G.)
B-2 = ESP
A-1 = venturi scrubber (25" W.G.)
A-2 = high energy ESP

For grinders:
A-1 = venturi scrubber (16" W.G.)
A-2 = fabric filter

(c) Incremental cost for installing and operating alternative control system (i.e., cost above the existing costs).

(d) Level of control for New Source Performance Standards.

6.1.9 Total Health Impact of Phosphate Rock Processing Plants

Phosphate rock processing plants (dryers and grinders) release about 3700 MT of particulate matter per year with the existing level of control (TRW82). This particulate matter contains about 150 mCi of uranium-238 and each of its daughter products. These emissions are estimated to cause about 1E-2 fatal cancers per year of operation. This estimate was derived from a ratio of the amount particulate matter released from all plants to the amount released from the reference facility:

$$\text{Number of fatal cancers per year from all plants} = \frac{3700\ \text{MT PM/yr}}{380\ \text{MT PM/yr}} \times 0.0013\ \text{HE/yr (reference facility)}$$

$$= 0.013$$

6.1.10 Costs and Risk Reductions for Retrofitting Existing Plants

The industry incremental annualized costs to retrofit existing phosphate dryer and grinding units are shown in Table 6.1-8.

To retrofit existing dryers with medium energy venturi scrubbers would cost an additional $6 million per year and would avoid 0.003 fatal cancers/year, or a cost of $1830 million per fatal cancer avoided. Retrofitting to the NSPS level (Control Option A) would cost an additional $12 million per year and avoid 0.008 fatal cancers per year, or a cost of $1530 million per fatal cancer avoided.

Retrofitting the existing grinders to the NSPS levels (Control Option A) would cost an additional $340,000 per year and avoid 0.0008 fatal cancers per year, or a cost of $430 million per fatal cancer avoided.

Table 6.1-8. Industry annualized costs and risk reductions for retrofitting existing phosphate rock dryers and grinders(a)

Process unit	Control option(b)	Total cost(c) (millions)	Fatal cancers avoided/y	Cost/fatal cancer avoided (in millions)
Dryers	B	5.5	3E-3	1830
	A	12.2	8E-3	1530
Grinders	A	0.34	8E-4	430

(a) TRW82.

(b) For dryers Option B is a venturi scrubber (15" W.G.) and Option A is a venturi scrubber (25" W.G.). For grinders, Option A is a fabric filter.

(c) Incremental cost for installing and operating alternative control system (i.e., costs above existing costs).

REFERENCES

DM68 Dames and Moore, Airborne Radioactive Emission Control Technology, Report on EPA Contract 68-01-4992, White Plains, New York, Unpublished.

EPA78 Environmental Protection Agency, Radiation Dose Estimates due to Air Particulate Emissions from Selected Phosphate Industry Operations, ORP/EERF-78-1, Office of Radiation Programs, Montgomery, Alabama, 1978.

EPA79 Environmental Protection Agency, Phosphate Rock Plants, Background Information for Proposed Standards, EPA-450/3-79-017, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, 1979.

TRW82 TRW, Particulate Emissions and Control Costs of Radionuclide Sources in Phosphate Rock Processing Plants. A report prepared by Stacy G. Smith (TRW Energy and Environmental Division, Research Triangle Park, N.C.) for Office of Radiation Programs, December 1982.

6.2 Wet Process Fertilizer Plants

6.2.1 General Description

Most phosphate rock produced in the United States is used for the production of high-analysis agricultural fertilizers. In 1976, 50 million metric tons of phosphate rock were used to produce 9 million metric tons of phosphoric acid, the starting material for ammonium phosphate and triple superphosphate fertilizers (EPA79).

6.2.2 Process Description

Wet process phosphoric acid is produced by mixing ground phosphate rock with 93 percent sulfuric acid and water. In the process gypsum (calcium sulfate) is produced as a byproduct. The simplified overall reaction is represented by:

$$3Ca_3(PO_4)_2 + 9H_2SO_4 = 6H_3PO_4 + 9CaSO_4 \qquad (1)$$

Phosphate rock is not the pure compound indicated above, but a fluoroappitite material containing minor quantities of flourine, iron, aluminum, silica and uranium. Following the reaction in the digester, the mixture of phosphoric acid and gypsum is pumped to a filter which mechanically separates the particulate gypsum from the phosphoric acid (approximately 30 percent phosphorus pentoxide concentration). An enormous amount of the byproduct gypsum is produced--each metric ton of phosphorus pentoxide, as phosphoric acid, produces approximately 5 metric tons of gypsum. Normally, the gypsum is sluiced with process water from the plant to the disposal area. The phosphoric acid separated from the gypsum is collected for further processing (EPA79).

The phosphoric acid is then used to produce several different grades of agricultural fertilizers. Triple superphosphate (TSP) fertilizer is made using ground phosphate rock and phosphoric acid as in the following equation:

$$Ca_3(PO_4)_2 + 4H_3PO_4 = 3Ca(H_2PO_4)_2 \qquad (2)$$

Ammonium phosphate fertilizer is made using ammonia and wet process phosphoric acid. Monoammonium phosphate (MAP) and diammonium phosphate (DAP) are produced as in the following equations:

$$H_3PO_4 + NH_3 = NH_4H_2PO_4 \qquad \text{MAP} \qquad (3)$$

$$H_3PO_4 + 2NH_3 = (NH_4)_2HPO_4 \qquad \text{DAP} \qquad (4)$$

The steps involved in the wet process production of agricultural fertilizers are summarized in Table 6.2-1. The major sources of radionuclide emission in particulate dust results in the product drying and handling areas.

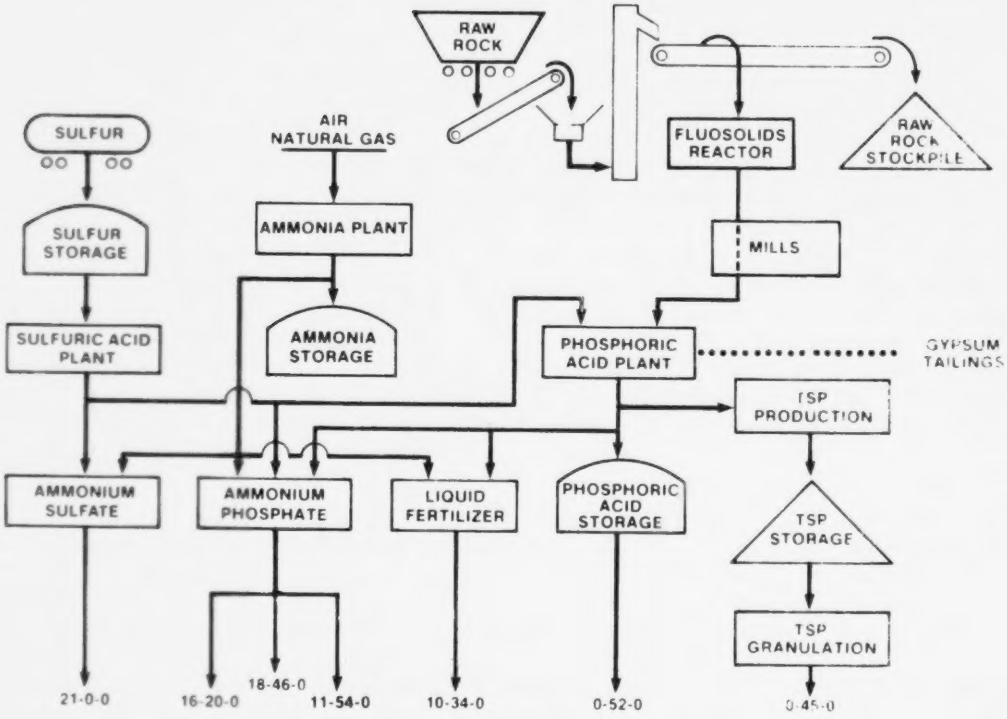

RAW ROCK
SULFUR
AIR
NATURAL GAS
FLUOSOLIDS REACTOR
RAW ROCK STOCKPILE
SULFUR STORAGE
AMMONIA PLANT
MILLS
SULFURIC ACID PLANT
AMMONIA STORAGE
PHOSPHORIC ACID PLANT
GYPSUM TAILINGS
TSP PRODUCTION
AMMONIUM SULFATE
AMMONIUM PHOSPHATE
LIQUID FERTILIZER
PHOSPHORIC ACID STORAGE
TSP STORAGE
TSP GRANULATION
21-0-0
16-20-0
18-46-0
11-54-0
10-34-0
0-52-0
0-45-0

Figure 6.2-1. Flow diagram of the wet process (EPA79).

6.2.3 Control Technology (TRW82)

Production processes for diammonium phosphate (DAP) and granular triple superphosphate (GTSP) are similar. The same process equipment in certain plants is used to produce both DAP and GTSP on an alternating basis; therefore, the control equipment for DAP and GTSP processes is similar. The particulate matter emission points within the DAP and GTSP production processes are as follows:

- reactor/granulator exhaust(s);
- dryer exhaust;
- cooler exhaust where appropriate; and
- screens, mills, and materials handling ventilation system(s) and exhaust(s).

Additional particulate matter (PM) emission sources exist in the ground rock raw materials handling (GTSP only) and final product handling systems (DAP and GTSP). These sources, however, are mostly "fugitive" sources and not process sources.

The DAP and GTSP processes currently in operation employ a variety of wet scrubbing systems on each of the major process exhaust streams. In most instances, scrubbers are installed in series. Generally, individual scrubbing systems are designated as "primary," "secondary," etc., referring to their order in the series of control devices.

Scrubbing systems have not been installed to control particulate matter; rather, process economic considerations and flouride emissions control have prompted installation of the scrubbing systems. In the DAP process, the primary scrubber uses phosphoric acid as a scrubbing solution to recover ammonia raw materials that otherwise would be lost. Without ammonia recovery, the cost of manufacturing DAP is not competitive. Secondary scrubbing systems have been installed by and large to control flouride emissions, to ensure worker safety, and to meet environmental regulations. Secondary scrubbing systems generally use recirculated process water (pond water) to enhance flouride removal. Some plants operate tertiary scrubbers for the same reasons. The primary, secondary, and sometimes tertiary scrubbing systems, however, also control particulate matter emissions.

The control technologies that can be applied to these PM emission sources include:

- cyclone systems
- wet scrubbing systems;
- bag filters; and
- electrostatic precipitators.

In practice, however, electrostatic precipitators have not been the technology of choice. Moreover, the use of bag filters has been limited to the cooler exhausts from certain processes and product screening, milling and handling ventilation system exhausts. This is primarily because the major PM emission points (the reactor granulator exhausts, dryer exhausts, and cooler exhausts on certain processes) are also emission points for other pollutants. In particular, gaseous flouride emissions (GTSP and DAP) and gaseous ammonia emissions (DAP only) are largely unaffected by electrostatic precipitators or baghouses. In addition, the moisture in the reactor and dryer exhaust streams and the sticky nature of the particulate matter in these streams complicates the use of bag filter devices. Consequently, PM control technologies applicable to DAP and GTSP production processes are realistically limited to dry cyclone systems, wet scrubbing systems, and bag filters (for dry materials handling sources only).

Dry cyclone systems are routinely employed on dryer, cooler, screens, and milling operation exhausts to recover entrained product that otherwise may be lost. As such, the cyclone systems are as much a part of the process as they are control equipment.

Controls in place were estimated in a survey of 14 plants (25 DAP and 14 GTSP processes) based on state air permit files and conversations with plant personnel. Although 100 percent of the DAP and GTSP production in the United States is not represented in the survey, based on published production capacity data, greater than 90 percent of domestic production is represented. It was found that primary scrubbing systems are employed on 100 percent of the existing processes. Venturi scrubbers make up about 60 to 95 percent of the primary scrubbers. In addition, secondary scrubbing systems are employed on about 60 to 80 percent of the existing processes. About half of the secondary scrubbers in the industry are packed bed scrubbers. Tertiary scrubbers also are employed on about 8 to 15 percent of the DAP process units (i.e. reactors, dryers, etc.) and 28 percent of the GTSP process units.

6.2.4 Radionuclide Emission Measurements

EPA has measured radionuclide emission in particulate stack releases at two wet process phosphate fertilizer plants (EPA78). The samples were collected on product dryer stacks in accordance with EPA guidelines established in the Code of Federal Regulations, Title 40, Part 60. The annual emission rates based on these measurements are listed in Table 6.2-1.

6.2.5 Reference Facility

Table 6.2-2 describes the parameters of a reference wet process phosphate fertilizer plant which are used to estimate the radionuclide emissions to the atmosphere and the resulting health impacts. The reference plant produces both diammonium phosphate (DAP) and granular triple superphosphate (GTSP) from phosphoric acid derived from phosphate rock. The radionuclide emissions to air from the DAP and GTSP process stacks of the reference facility are listed in Table 6.2-3. The emissions are representative of plants using only primary scrubbers to control DAP and GTSP process off gases.

Table 6.2-1. Radionuclide stack emissions at wet process phosphate fertilizer plants (EPA78)

Parameter	TSP dryer Plant A	TSP dryer Plant B	DAP dryer Plant B
Total particulates (g/y)	2.0E+7	1.2E+7	1.5E+7
Operating time (hr/y)	4.6E+3	7.4E+3	7.5E+3
Stack emissions (Ci/y)			
Uranium-234	1.1E-4	3.0E-4	2.6E-3
Uranium-235	ND	2.0E-5	1.9E-4
Uranium-238	9.0E-5	2.7E-4	3.3E-3
Thorium-227	ND	ND	ND
Thorium-228	4.0E-5	3.0E-5	8.0E-5
Thorium-230	9.0E-5	2.5E-4	3.0E-3
Thorium-232	ND	7.0E-5	5.0E-5
Radium-226	3.0E-5	2.2E-4	2.6E-4
Polonium-210	6.3E-4	NA	NA

ND Not detectable.
NA Not available.

6.2.6 Health Impact Assessment of Reference Plant

The estimated annual radiation doses from radionuclide emissions from the reference wet process phosphate fertilizer plant are listed in Table 6.2-4. These estimates are for a model site in central Florida with a regional population of 1.4E+6. The nearby individuals are located 1500 meters south of the reference plant.

Table 6.2-5 presents estimates of the lifetime risk to nearby individuals and the number of fatal cancers per year of operation from these doses.

The lifetime risk to nearby individuals is estimated to be about 2E-6 and the number of fatal cancers per year of operation is estimated to be 6E-4. These risks result primarily from doses to the lung from inhalation of radioactive particulates released from fertilizer production.

6.2.7 Existing Emission Standards and Air Pollution Controls

No Federal or State regulations currently exist that limit radionuclide emissions from wet process phosphate fertilizer plants. Particulate emissions from these facilities are limited to the quantities established by the States in their State Implementation Plans (SIPs) for meeting Ambient Air Quality Standards.

Florida, where almost 80 percent of the industry is located, has the most stringent SIP limits. Phosphate processing operations are limited to 0.3 lb/ton of product (150 g/MT of product). The other States with wet process phosphate fertilizer plants have not established specific emission limits for phosphate processing, but restrict emissions to the levels established in their SIPs for general processing sources. For sources greater than 30 tons/hour, allowable emissions are determined by the formula:

$$E = (55.0 \times P0.11)-40,$$

where

E = emissions, and

P = the processing rate in tons/hour.

6.2.8 Alternative Control Technology

All wet process phosphate fertilizer plants use primary scrubbers on the DAP and GTSP exhausts. The annualized costs and risk reduction of adding alternative controls to the reference wet process phosphate fertilizer plant are shown in Table 6.2-6.

Table 6.2-2. Reference wet process phosphate fertilizer plant

Parameter	Process	
	DAP	GTSP
Production rate (MT/y)	5.2E+5	2.7E+5
Operating factor (hr/y)	8160	8160
Radionuclide content of product (pCi/g)(a)		
Uranium-238, uranium-234, thorium-230	60	60
Radium-226	5	20
Lead-210, polonium-210	30	30
Stack parameters		
Height (meters)	40	40
Diameter (meters)	2	2
Exit gas velocity (m/s)	10	10
Exit gas temperature (°C)	60	60
Type of control system	Venturi scrubber	Venturi scrubber
Particulate emission rate (g/MT)	164	100

(a) Data from EPA78. DAP Diammonium phosphate.
GTSP Granular triple superphosphate.

Table 6.2-3. Radionuclide emissions from the reference wet process phosphate fertilizer plant

Radionuclide	Emissions (Ci/y)		
	DAP	GTSP	Total
Uranium-238	5.1E-3	1.6E-3	6.7E-3
Uranium-234	5.1E-3	1.6E-3	6.7E-3
Thorium-230	5.1E-3	1.6E-3	6.7E-3
Radium-226	4.3E-4	5.4E-4	9.7E-4
Lead-210	2.6E-3	8.1E-4	3.4E-3
Polonium-210	2.6E-3	8.1E-4	3.4E-3

DAP Diammonium phosphate.
GTSP Granular triple superphosphate.

Table 6.2-4. Radiation dose rates from radionuclide emissions from the reference wet process phosphate fertilizer plant

Organ	Nearby individuals (mrem/y)	Regional population (Person-rem/y)
Lung	1.2	2.4E+1
Endosteum	2.2	4.1E+1
Red marrow	1.5E-1	2.8
Kidney	6.7E-2	1.3

Table 6.2-5. Fatal cancer risks due to radioactive emissions from reference wet process phosphate fertilizer plant

Source	Lifetime risk to nearby individuals	Regional population fatal cancers/y of operation
DAP and GTSP process emissions	2E-6	6E-4

DAP Diammonium phosphate.
GTSP Granular triple superphosphate.

6.2.9 Total Health Impact of Wet Process Phosphate Fertilizer Plants

Wet process phosphate fertilizer plants release about 1500 MT per year of particulates from the DAP and GTSP process stacks with the existing control systems. This amount of particulate matter contains about 90 mCi each of uranium-238, uranium-234, and thorium-230 and lesser quantities of radium-226, polonium-210, and lead-210. This estimate is based on the conservative assumption that the specific activity (pCi/g) of the particulate material released is the same as DAP and GTSP fertilizers. These emissions are estimated to cause about 0.01 fatal cancers per year. This estimate is based on a ratio of the amount of particulate material released from all plants to the amount released from the reference plant in a manner similar to that shown in Section 6.1.8.

6.2.10 Costs and Risk Reductions for Retrofitting Existing Plants

The annualized costs to the industry to retrofit existing phosphate fertilizer plants with secondary scrubbers are shown in Table 6.1-7. To retrofit existing DAP process exhausts with packed bed scrubbers (28 percent of the existing production capacity) would cost an additional $3 million per year and would avoid 0.001 fatal cancers per year, or a cost of $3 billion per fatal cancer avoided. Retrofitting GSTP process exhausts with packed bed scrubbers (19 percent of existing production capacity) would cost an additional $500,000 per year and would avoid 0.0004 fatal cancers per year, or a cost of $13 billion per fatal cancer avoided.

Table 6.2-6. Annualized costs and risk reductions of alternative controls for the reference wet process phosphate fertilizer plant[(a)]

Process	Control option[(b)]	Emission rate[(c)] (g/MT)	Total annual cost ($1,000)	Fatal cancer risks		Cost/fatal cancer avoided (in millions)
				Individual lifetime risk	Population (cancers/y of operation)	
DAP	Existing	164		2E-6	5E-4	
	Alternative	100	500	1E-6	3E-4	2.5E+3
GTSP	Existing	100		5E-7	1E-4	
	Alternative	79	300	4E-7	8E-5	1.5E+4

DAP Diammonium phosphate GTSP Granular triple superphosphate.

(a) Source: TRW82.

(b) Existing controls are venturi scrubbers. Alternative controls are packed bed scrubbers in series with venturi scrubbers.

(c) Particulate material emission rate.

(d) Incremental cost for installing and operating alternative control systems, i.e., additional costs for installing and operating packed bed scrubbers.

Table 6.2-7. Industry annualized costs and risk reductions for adding secondary scrubbers to existing wet process phosphate fertilizer plants(a)

Process	Total cost (millions)(b)	Fatal cancers avoided/y	Cost/fatal cancer avoided (in millions)
DAP	3	1E-3	3E+3
GTSP	0.5	4E-5	1.3E+4

(a) TRW82.

(b) Incremental cost of installing and operating packed bed scrubbers in series with existing venturi scrubbers. Twenty-eight percent of DAP production capacity and 19 percent of GTSP production capacity require retrofit.

DAP Diammonium phosphate.
GTSP Granular triple superphosphate.

REFERENCES

EPA78 Environmental Protection Agency, Radiation Dose Estimates due to Air Particulate Emissions from Selected Phosphate Industry Operations, ORP/EERF-78-1, Office of Radiation Programs, Montgomery, Alabama, 1978.

EPA79 Environmental Protection Agency, Radiological Impact Caused by Emissions of Radionuclides into Air in the United States, EPA-520/7-79-006, Office of Radiation Programs, Washington, D.C., 1979.

TRW82 TRW, Industry and Particulate Matter Control Technology Information for Diammonium Phosphate and Granular triple Superphosphate manufacture. A report prepared by TRW Environmental Division for the Environmental Protection Agency, Dec 15, 1982.

6.3 Elemental Phosphorus Plants

6.3.1 General Description

About ten percent of the marketable phosphate rock mined in the United States is used for the production of elemental phosphorus. Elemental phosphorus is used primarily for the production of high grade phosphoric acid, phosphate-based detergents, and organic chemicals. In 1983 approximately 366 thousand tons of elemental phosphorus were produced.

Phosphate rock contains appreciable quantities of uranium and its decay products. The uranium concentration of phosphate rock ranges from about 20 to 200 ppm, which is 10 to 100 times higher than the uranium concentration in typical rocks and soil (2 ppm). The radionuclides of significance which are present in phosphate rock are: uranium-238, uranium-234, thorium-230, radium-226, radon-222, lead-210, and polonium-210. Because phosphate rock contains elevated concentrations of these radionuclides, handling and processing this material can release radionuclides into the air in the form of dust particles. More importantly for elemental phosphorus plants, heating the phosphate rock to high temperatures in calciners and electric furnaces can volatilize lead-210 and polonium-210, resulting in the release of significant quantities of these radionuclides into the air.

There are 6 elemental phosphorus plants in the United States--located in Idaho, Montana, and Tennessee. Table 6.3-1 shows the owners, locations, and the estimated elemental phosphorus production rates for these plants.

6.3.2 Process Description

Phosphate rock which has been crushed and screened is fed into calciners where it is heated to the melting point, usually 1300° C. The calcining serves two purposes: (1) it burns any organic matter present in the rock, and (2) it transforms the finely divided rock into large stable agglomerates or nodules which are needed for proper operation of the reduction furnaces. The hot nodules are passed through coolers and then to storage bins prior to being fed to electric furnaces. The furnace feed consists of the nodules, silica and coke. The proper amount of silica is needed to form slag with the flow properties necessary to facilitate removal from the furnace. Coke is added as a carbon source to reduce the calcium phosphate to elemental phosphorus. A simplified chemical equation for the electric furnace reactor is as follows:

$$2Ca_3(PO_4)_2 + 6SiO_2 + 10C = P_4 + 10CO + 6CaSiO_3 \qquad (1)$$

In addition, the iron naturally present in the rock reacts with some of the phosphorus to produce FeP. The blended furnace feed enters the furnaces continually from the top and progresses downward until reaching the molten layer on the bottom. Phosphorus and carbon monoxide (CO) are driven off as gases and are vented near the top of the furnace. The slag and FeP which are continually collecting in the furnace are periodically "tapped off."

Furnace off-gases pass through dust collectors and then through water spray condensors. Phosphorus is cooled to the molten state in the condensors. The mix of phosphorus and water--phossy water--and mud go to a processing system where phosphorus is separated and piped to storage. The clean off-gases leaving the condensors contain a high concentration of CO and are used as fuel in the calciners. A flow diagram of the process is shown in Figure 6.3-1.

Table 6.3-1. Location and size of elemental phosphorus plants

Location	Company	Capacity[(a)] (tons/y of phosphorus)
Idaho		
Pocatello	FMC Corporation	1.3E+5
Soda Springs	Monsanto Chemical Co.	9.0E+4
Montana		
Silver Bow	Stauffer Chemical Co.	4.0E+4
Tennessee		
Columbia	Occidental Chemical Co.	5.7E+4
Columbia	Monsanto Chemical Co.	7.5E+4
Mt. Pleasant	Stauffer Chemical Co.	5.0E+4

(a) Estimated capacity in 1984 (EPA84d).

6.3.3 Control Technology

Emissions from calciners are typically controlled by low energy scrubbers. Emissions from nodule coolers and transfer points and furnace tap holes are controlled by either fabric filters or wet scrubbers. Screening plant emissions are usually controlled by fabric filters. Fugitive dust emissions and radon gas emissions are not controlled.

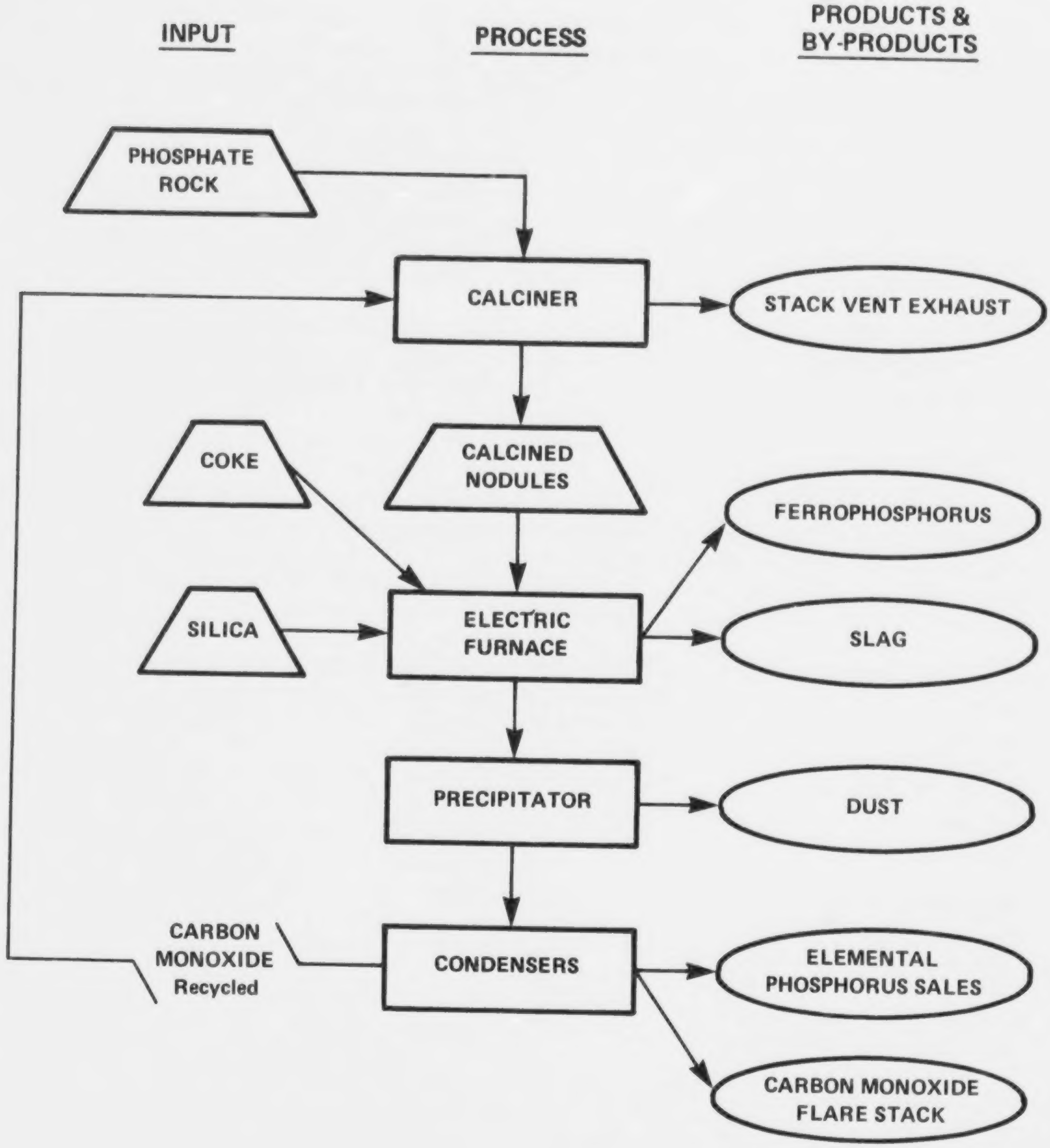

INPUT
PROCESS
PRODUCTS & BY-PRODUCTS
PHOSPHATE ROCK
CALCINER
STACK VENT EXHAUST
COKE
CALCINED NODULES
FERROPHOSPHORUS
SILICA
ELECTRIC FURNACE
SLAG
PRECIPITATOR
DUST
CARBON MONOXIDE Recycled
CONDENSERS
ELEMENTAL PHOSPHORUS SALES
CARBON MONOXIDE FLARE STACK

Figure 6.3-1. Flow diagram of the thermal process for production of elemental phosphorus.

6.3.4 Radionuclide Emission Measurements

In the period 1975-1980, EPA measured the radionuclide emission rates from three elemental phosphorus plants. These plants were: FMC in Pocatello, Idaho (EPA77), Stauffer in Silver Bow, Montana (An81a), and Monsanto in Columbia, Tennessee (An81b). These tests included measurements from release points representative of all of the major process operations in the production of elemental phosphorus. Measurements were made of the emission rates from: calciners, calciner coolers, material handling and transfer operations, screening plants, furnace preparation areas, and furnace tap holes. The stack emission rates measured during these studies are summarized in Table 6.3-2.

All of the radionuclides are released as particulates except for radon-222, which is released as a gas. Essentially all of the radon-222 and greater than 95 percent of the lead-210 and polonium-210 emitted from these facilities are released from the calciner stacks. The high temperature of the calciners volatilizes the lead-210 and polonium-210 from the phosphate rock, resulting in the release of much greater quantities of these radionuclides than the uranium, thorium and radium radionuclides. Analyses of doses and risks from these emissions show the emissions of polonium-210 and, to a lesser degree, emissions of lead-210 to be the major contributors to risk from radionuclide emissions from elemental phosphorus plants (see Section 6.3.5).

In late 1983, EPA conducted extensive additional radionuclide emission testing at the FMC plant in Pocatello, Idaho (EPA84a, RC84a), and the Stauffer plant in Silver Bow, Montana (EPA84b, RC84b). Also in early 1984, EPA conducted some limited emission testing at the Monsanto plant in Soda Springs, Idaho (EPA84c, RC84c). This testing was limited to calciner off-gas streams (based on results of previous emission testing) and focused primarily on lead-210 and polonium-210 emissions. The principal objectives of these tests were: (1) to obtain additional information on the lead-210 and polonium-210 emissions in calciner off-gas streams, (2) to determine the distribution of lead-210 and polonium-210 by particle size in calciner off-gas streams, and (3) to obtain a suitable sample for determining the lung-clearance classification of lead-210 and polonium-210 in particulates collected from the calciner off-gas streams.

Reports on this testing have been prepared for each plant as cited in the above noted references. These reports contain the following data and information: (1) radionuclide concentrations in the calciner feed material and the calcined product (nodules), (2) radionuclide and particulate concentrations and emission rates in calciner off-gas streams including both inlet and outlet streams of emission control devices, (3) particle size distribution of both radionuclides and particulates in calciner off-gas streams including the distribution for both inlet and outlet streams of emission control devices, (4) estimates of the annual emission rates for both radionuclides and

Table 6.3-2. Radionuclide stack emissions measured at elemental phosphorus plants (1975-1980)(a)

Parameter	FMC Idaho	Stauffer Montana	Monsanto Tennessee
Rock processing rate (MT/y)(b)	1.6E+6	5.3E+5	1.7E+6
Uranium-238 concentration of rock (pCi/g)(c)	22.0	27.0	5.0(d)
Calciner stacks emission rate (Ci/y):(e)			
Uranium-238	1.2E-3	2.4E-4	2.2E-3
Uranium-234	1.3E-3	2.0E-4	3.2E-3
Thorium-230	2.2E-3	1.2E-4	1.4E-3
Radium-226	1.3E-3	3.5E-4	2.1E-3
Radon-222	-	8.0	9.6
Lead-210	3.0E-3	2.8E-1	4.8E-1
Polonium-210	6.9	2.0E-1	7.5E-1
Other stacks emission rate (Ci/y):			
Uranium-238	4.0E-2	6.2E-4	1.0E-2
Uranium-234	4.6E-2	7.0E-4	1.0E-2
Thorium-230	5.3E-3	1.2E-3	1.2E-2
Radium-226	5.9E-3	1.1E-3	9.0E-3
Radon-222	-	ND	ND
Lead-210	1.5E-2	2.5E-3	ND
Polonium-210	4.0E-1	5.9E-3	2.7E-3
Fraction of input radionuclides emitted:			
Uranium-238	1.2E-3	6.0E-5	1.4E-3
Uranium-234	1.4E-3	6.2E-5	1.5E-3
Thorium-230	2.1E-4	9.0E-5	1.5E-3
Radium-226	2.0E-4	9.8E-5	1.7E-3
Radon-222	-	5.7E-1	1.1
Lead-210	5.1E-4	2.0E-2	5.6E-2
Polonium-210	2.1E-1	1.4E-2	8.8E-2

(a) Emissions are in particulate form except for radon-222 which is released in gaseous form.

(b) These processing rates were those estimated for these plants at time of emission testing.

(c) Uranium-238 and its daughter products are assumed to be present in equilibrium in the rock.

(d) Calciner feed material was a blend of Tennessee and Florida phosphate rock.

(e) Based on 8760 hours of plant operation.

particulates, (5) estimates of the efficiency of existing control systems in removing radionuclides and particulates, (6) descriptions of the sampling methods and procedures used during the testing, and (7) test parameters, such as sample volumes and flow rates used in testing.

A brief description of the major results obtained during this testing is presented in the following sections.

The limited sampling at the Monsanto, Soda Springs, Idaho, plant was due to the unavailability of suitable sampling locations for more detailed testing. The Monsanto plant releases its calciner off-gas stream through a large diameter demister. Significant modifications to the demister and installation of a stack extension are necessary before emission testing equivalent to that conducted at FMC and Stauffer can be made at the Monsanto plant. (For more details on sampling problems at the Monsanto plant see RC84c.)

Results of 1983-1984 Emission Testing

Process Samples

Table 6.3-3 presents the measured radionuclide concentrations in the calciner feed material and product samples for the three plants studied. For the Stauffer and Monsanto plants, both the lead-210 and polonium-210 concentrations in the calciner product samples were significantly lower than the concentrations in the feed material, reflecting the volatilization of these radionuclides during the calcining operation. For the FMC plant, only the polonium-210 concentration was significantly lower in the product samples than in the feed material. This indicates that large quantities of lead-210 are not volatilized during the calcining operation at the FMC plant.

Radionuclide Emission Rates

Table 6.3-4 presents the measured radionuclide emission rates for the three plants studied in μCi/hr/calciner and the estimated annual calciner emission rates. The estimated annual polonium-210 emission rates are: Monsanto, Soda Springs, Idaho = 21 Ci/yr; FMC, Pocatello, Idaho = 8.6 Ci/yr; and Stauffer, Silver Bow, Montana = 0.74 Ci/yr. The estimated annual lead-210 emission rates are: Monsanto, Soda Springs, Idaho = 5.6 Ci/yr; FMC, Pocatello, Idaho = 0.12 Ci/yr; and Stauffer, Silver Bow, Montana = 0.11 Ci/yr.

Particle Size Distribution

Table 6.3-5 presents the measured distribution of lead-210 and polonium-210 by particle size in the calciner off-gas streams at the FMC and Stauffer plants. These samples were collected using Andersen cascade impactors. Similar samples could not be collected at the

Monsanto plant because suitable sampling ports and locations were not available (RC84c). These data show that for both the FMC and Stauffer plants, most of the polonium-210 was associated with submicron particles. For the FMC plant, an average of 73 percent of the polonium-210 was in a particle size range less than 0.5 microns and 86 percent was in a range less than 1.5 microns. For the Stauffer plant, an average of 53 percent of the polonium-210 was in a particle size range less than 0.5 microns, and about 90 percent was in a range less than 1.5 microns.

Table 6.3-3. Measured radionuclide concentrations in process samples at elemental phosphorus plants (1983-1984 emission test results)

Plant	Radionuclide concentrations (pCi/g)					
	Feedstock			Calcined product		
	Uranium-238	Lead-210	Polonium-210	Uranium-238	Lead-210	Polonium-210
FMC Pocatello, Idaho	21	26	21	22	27	8
Stauffer Silver Bow, Montana	42	46	40	42	7	4
Monsanto Soda Springs, Idaho(a)	32	150	91	37	6	2

(a)Blended feed material. This plant recycles both dropout chamber dust and underflow solids from wet scrubber clarifier.

Table 6.3-4. Radionuclide emissions from calciners at elemental phosphorus plant (1983-1984 emission test results)

Plant	Average measured radionuclide emissions (μCi/h/calciner)(a)			Number of calciners	Estimated total calciner emissions (Ci/y)(b)(c)		
	Uranium-238	Lead-210	Polonium-210		Uranium-238	Lead-210	Polonium-210
FMC Pocatello, Idaho	0.28	7.5	540	2	0.004	0.12	8.6
Stauffer Silver Bow, Montana	0.04	7.6	50	2	0.0006	0.11	0.74
Monsanto Soda Springs, Idaho	0.78	760	2900	1	0.006	5.6	21

(a) For the FMC plant, emission rates were measured from both calciner units, and the reported values are the average emission rates for these units. For the Stauffer plant, emissions for only one of the calciner units (kiln-2) were measured, and the reported values are the average value for this unit. In estimating total annual emissions, it was assumed that both calciner units have the same emission rates.

(b) Based on 7400 hours of calciner operation (i.e., 85 percent operating factor).

(c) The conversion of measured emission rates to annual emission estimates for the FMC plant includes an adjustment for processing rate where applicable (see EPA84a).

Table 6.3-5. Measured distribution of lead-210 and polonium-210 by particle size in calciner stack outlet streams at elemental phosphorus plants (1983 emission test results)[a]

Plant	Approximate particle size range (D-50)(microns)	Percent of total	
		Lead-210	Polonium-210
FMC Pocatello, Idaho	>10	10	7
	3-10	13	5
	1.5-3	9	4
	0.9-1.5	10	6
	0.5-0.9	14	5
	<0.5	44	73
Stauffer Silver Bow, Montana	>10	<1	2
	3-10	3	4
	1.5-3	5	4
	0.9-1.5	14	17
	0.5-0.9	22	25
	<0.5	53	50

[a] Particle size measurement using cascade impactors could not be made at Monsanto, Soda Springs, Idaho, because suitable sampling ports and locations were not available.

Lung-Clearance Classification Studies

Samples of particulates collected from the calciner off-gas streams at FMC and Stauffer were sent to the Pacific Northwest Laboratory for testing to determine the lung-clearance classifications (for use in ICRP lung model)(ICRP66) of lead-210 and polonium-210 in these particulates. These lung-clearance classifications were determined by measuring dissolution rates of these radionuclides in simulated lung fluid. For each plant, testing was conducted on samples containing particulates in the range of 0 to 3 microns and 3 to 10 microns. A detailed description of the test methods used and results obtained are presented in PNL-5221 (Ka84). Table 6.3-6 summarizes the dissolution data for lead-210 and polonium-210 in simulated lung fluid for these particulate samples.

The results of these tests show that both the lead-210 and the polonium-210 dissolved only very slowly in the simulated lung fluid. More than 99 percent of these radionuclides remained undissolved even after 60 days of testing. Based on these tests, it was concluded that both lead-210 and polonium-210 in these materials should be considered Class Y for calculations with the ICRP lung model (i.e., the model used in EPA in dose calculations).

Table 6.3-6. Dissolution of lead-210 and polonium-210 from particulate samples collected from off-gas streams at FMC and Stauffer elemental phosphorus plants

Plant	Sample particle size (micron)	Dissolution time (days)	Fraction of ^{210}Pb remaining undissolved	Fraction of ^{210}Po remaining undissolved
FMC Pocatello, Idaho	0-3	1.0	0.9984	0.9997
		3.0	0.9973	0.9990
		10.0	0.9968	0.9984
		20.2	0.9962	0.9980
		37.0	0.9956	0.9979
		59.0	0.9950	0.9978
	3-10	1.0	0.9933	0.9991
		3.0	0.9744	0.9988
		10.0	0.9682	0.9979
		20.2	0.9618	0.9970
		37.0	0.9554	0.9943
		59.0	0.9490	0.9914
Stauffer Silver Bow, Montana	0-3	1.0	0.9999	0.9997
		2.9	0.9999	0.9996
		8.9	0.9994	0.9989
		20.8	0.9991	0.9986
		40.8	0.9983	0.9981
		59.0	0.9978	0.9980
	3-10	1.0	1.0000	0.9997
		2.9	0.9999	0.9993
		8.9	0.9990	0.9992
		20.8	0.9991	0.9948
		40.8	0.9985	0.9942
		59.0	0.9979	0.9940

6.3.5 Health Impact Assessment of Elemental Phosphorus Plants

Tables 6.3-7 and 6.3-8 show the estimated annual calciner emission rates and stack parameters for each of the six operational elemental phosphorus plants. These values were used in estimating the radiation doses and fatal cancer risks from these plants.

Table 6.3-9 presents the radiation doses to the lung from radionuclide emissions from calciners at elemental phosphorus plants. Almost all of the radiation risk from radionuclide emissions from calciners at these plants results from these lung doses. The lung-clearance classifications and particle size distributions (AMAD) used in estimating these doses (ICRP Task Group Lung Model) are shown below:

Radionuclide	Clearance Classification	Particle Size AMAD
Lead-210, Polonium-210	Y[a]	0.3[a]
Uranium-238, Uranium-234, Thorium-230	Y[b]	1[b]
Radium-226	W[b]	1[b]

---

[a] Based on experimental data obtained during emission testing.

[b] Based on values recommended by ICRP (ICRP66) when experimental values not available.

Table 6.3-10 presents estimates of the lifetime risk to the nearby individuals and the number of fatal cancers to the regional population from radionuclide emissions from calciners at elemental phosphorus plants. The doses and risks to the nearby individuals were calculated for a location 1500 meters from the plant in the predominant wind direction. The doses and risks to the regional population were calculated using the population distribution of the actual plant site. Table 6.3-11 shows the number of people living within 80 km of these sites and the source of the meteorological data used in these calculations.

The fatal cancer risks from radionuclide emissions from calciners at elemental phosphorus plants result primarily from inhalation of polonium-210. To illustrate this point, Tables 6.3-12 through 6.3-15 show the doses to the various organs and the relative significance of various pathways, organs, and radionuclides to the fatal cancer risks from radionuclide emissions from calciners at both the FMC and Monsanto, Idaho, plants.

Table 6.3-7. Estimated annual radionuclide emissions from elemental phosphorus plants[a]

Plant	Emissions (Ci/y)		
	Uranium-238[b]	Lead-210	Polonium-210
FMC[c] Pocatello, Idaho	4E-3	0.1	9
Monsanto[c] Soda Springs, Idaho	6E-3	5.6	21
Monsanto[c] Columbia, Tennessee	2E-3	0.4	0.6
Stauffer[c] Silver Bow, Montana	6E-4	0.1	0.7
Stauffer[d] Mt. Pleasant, Tennessee	2E-4	0.05	0.1
Occidental[d] Columbia, Tennessee	2E-4	0.05	0.1

[a] Emission rates based on 7400 hrs per year of calciner operation (i.e., 85 percent operating factor).

[b] In using these data in estimating radiation doses and risks for these plants, equal quantities of uranium-234, thorium-230, and radium-226 were assumed to be emitted along with the uranium-238. This assumption is supported by data in Table 6.3-2 which shows that uranium-238 is in equilibrium (within about a factor of 2) with uranium-234, thorium-230, and radium-226 in the calciner off-gas streams. In any case, however, as noted previously, these radionuclides do not contribute significantly to the doses and risks from radionuclide emissions from calciners at elemental phosphorus plants.

[c] Based on measurements during EPA testing.

[d] Estimates based on the following percent releases of radionuclides entering the calciners: polonium-210 = 10 percent, lead-210 = 5 percent uranium-238 = 0.02 percent (i.e., similar to percent releases for the reference plant in EPA83).

Table 6.3-8. Calciner stack emission characteristics

Plant	Stack height (meters)	Heat emission (calories/sec)
FMC Pocatello, Idaho	30	8.8E+5
Monsanto Soda Springs, Idaho	31	2.0E+6
Monsanto Columbia, Tennessee	35	1.0E+6
Stauffer Silver Bow, Montana	27	3.0E+4
Stauffer Mt. Pleasant, Tennessee	35	6.0E+5
Occidental Columbia, Tennessee	31	1.2E+6

Table 6.3-9. Radiation dose to lung from radionuclide emissions from elemental phosphorus plants

Plant	Nearby individuals Lung (mrem/y)	Regional population Lung (person-rem/y)
FMC Pocatello, Idaho	290	1170
Monsanto Soda Springs, Idaho	610	750
Monsanto Columbia, Tennessee	30	310
Stauffer Silver Bow, Montana	60	122
Stauffer Mt. Pleasant, Tennessee	6	33
Occidental Columbia, Tennessee	5	65

Table 6.3-10. Fatal cancer risks from radionuclide emissions from elemental phosphorus plants

Plant	Lifetime risk to nearby individuals	Regional population (Fatal cancers/y of operation)
FMC Pocatello, Idaho	5E-4	0.027
Monsanto Soda Springs, Idaho	1E-3	0.018
Monsanto Columbia, Tennessee	6E-5	0.007
Stauffer Silver Bow, Montana	1E-4	0.003
Stauffer Mt. Pleasant, Tennessee	1E-5	0.001
Occidental Columbia, Tennessee	9E-6	0.002

Table 6.3-11. Population within 80 km of elemental phosphorus plants and source of meteorological data used in dose and risk calculations

Plant	Number of people within 80 km(a)	Source of meteorological data(b)
FMC Pocatello, Idaho	1.4E+5	Pocatello, Idaho
Monsanto Soda Springs, Idaho	8.0E+4	Pocatello, Idaho
Stauffer Silver Bow, Wyoming	7.7E+4	Butte, Montana
Monsanto Columbia, Tennessee	7.7E+5	Nashville, Tennessee
Stauffer Mt. Pleasant, Tennessee	6.0E+5	Nashville, Tennessee
Occidental Columbia, Tennessee	8.0E+5	Nashville, Tennessee

(a)Based on 1970 Census.
(b)Data from National Climatic Center, Asheville, North Carolina.

Table 6.3-12. Radiation dose rates to various organs from radionuclide emissions from calciners at elemental phosphorus plants[a]

Organ	FMC Pocatello, Idaho (mrem/y)	Monsanto Soda Springs, Idaho (mrem/y)
Lung	290	610
Kidney	10	18
Liver	2	4
Endosteum	1	6
Red Marrow	0.3	0.9

(a)Doses to individuals located 1500 meters from the plant in predominant wind direction.

Table 6.3-13. Fatal cancer risks to nearby individuals from radionuclide emissions from calciners at elemental phosphorus plants by cancer type

Cancer	Lifetime risk to nearby individuals	
	FMC Pocatello, Idaho	Monsanto Soda Springs, Idaho
Lung	5E-4	1E-3
Urinary	2E-6	3E-6
Liver	1E-6	2E-6
Lukemia	3E-7	9E-7
Bone	3E-8	1E-7

Table 6.3-14. Fatal cancer risks to nearby individuals from radionuclide emissions from calciners at elemental phosphorus plants by radionuclide[a]

Radionuclide	Percent of total risk	
	FMC Pocatello, Idaho	Monsanto Soda Springs, Idaho
Uranium-234, -238	0.2	0.2
Thorium-230	0.1	0.1
Radium-226	0.01	0.01
Lead-210	1	26
Polonium-210	98	74

[a] These estimates do not include contributions from radon-222 emissions from the calciner. However, previous estimates (EPA83) showed that radon-222 emissions from calciners at elemental phosphorus plants cause only small additional fatal cancer risks, i.e., about one percent of the total risk.

Table 6.3-15. Fatal cancer risks to nearby individuals from radionuclide emissions from calciners at elemental phosphorus plants by pathway

Pathway	Percent of total risk	
	FMC Pocatello, Idaho	Monsanto Soda Springs, Idaho
Inhalation	99.3	99.5
Ingestion[a]	0.7	0.5
Other	<0.1	<0.1

[a] Food intakes used were those for an urban/low productivity site (see Appendix A).

6.3.6 Alternative Control Technology

An analysis of the cost and polonium-210 removal efficiency for alternative control systems for reducing polonium-210 emissions from calciner off-gas streams at the FMC and Monsanto Idaho plants was carried out for EPA by the Midwest Research Institute (MRI84a, MRI84b). A summary of these analyses is shown in Table 6.3-16. These plants were analyzed because they have the highest polonium-210 emissions. Reducing the polonium-210 emissions will also reduce the lead-210 emissions.

Tables 6.3-17 and 6.3-18 show the risk reduction and cost of control at various selected polonium-210 emission rates for the FMC and Monsanto (Idaho) plants, respectively. A more detailed analysis of the costs and risk reductions, as well as the economic impacts, of alternative polonium-210 emission rates for these plants is presented in a regulatory impact analysis of emission standards prepared for EPA by Jack Faucett Associates (EPA84d).

Table 6.3-16. Cost of alternative control systems for reducing polonium-210 emissions at FMC and Monsanto elemental phosphorus plants[(a)]

Control system	210-Po removal (%)	FMC Plant		Monsanto Plant	
		Capital cost ($ millions)	Annualized cost ($ millions)	Capital cost ($ millions)	Annualized cost ($ millions)
Scrubber					
15-in ΔP	65	2.1	1.6	1.1	0.9
30-in ΔP	77	2.8	2.5	1.5	1.4
45-in ΔP	83	3.7	3.5	2.0	2.0
ESP					
200 SCA[(b)]	72	5.2	1.4	2.9	0.8
300 SCA	83	5.9	1.5	3.2	0.9
400 SCA	90	6.7	1.7	4.3	1.1
Fabric filter	98	7.3	1.9	4.2	1.3

(a) From Midwest Research Institute Reports (MRI84a and MRI84b) and based on January 1984 dollars.

(b) SCA-Specific Collection Area in ft^2/1000 acfm.

Table 6.3-17. Cost of added controls and risk reduction at selected polonium-210 emission rates from calciners at FMC plant

Polonium-210 emission rate (Ci/y)	Fatal cancer risks		Risk reduction	Control system	Cost ($ millions)	
	Lifetime risk to nearby individuals	Regional population (Fatal cancers/y of operation)	Regional population (Fatal cancers/y of operation)		capital-	annualized
Current emissions	5E-4	0.027	---	---	---	---
2.5	1E-4	0.008	0.019	Medium energy ESP	5.9	1.5
1	5E-5	0.003	0.024	High energy ESP	6.7	1.7

Table 6.3-18. Cost of added controls and risk reductions at selected polonium-210 emission rates from calciners at Monsanto (Idaho) Plant

Polonium-210 emission rate (Ci/y)	Fatal cancer risks		Risk reduction	Control system	Cost ($ millions)	
	Lifetime risk to nearby individuals	Regional population (Fatal cancers/y of operation)	Regional population (Fatal cancers/y of operation)		capital-	annualized
Current emissions	1E-3	0.018	---	---	---	---
10	5E-4	0.009	0.009	15 in ΔP scrubber	1.1	0.9
2.5	1E-4	0.002	0.016	High energy ESP	4.3	1.1
1.0	5E-5	0.001	0.017	Fabric filter	4.2	1.3

REFERENCES

An81a Andrews V. E., Emissions of Naturally Occurring Radioactivity from Stauffer Elemental Phosphorus Plant, ORP/LV-81-4, EPA, Office of Radiation Programs, Las Vegas, Nevada, August 1981.

An81b Andrews V. E., Emissions of Naturally Occurring Radioactivity from Monsanto Elemental Phosphorus Plant, ORP/LV-81-5, EPA, Office of Radiation Programs, Las Vegas, Nevada, August 1981.

EPA77 Environmental Protection Agency, Radiological Surveys of Idaho Phosphate Ore Processing--The Thermal Plant, ORP/LV-77-3, EPA, Office of Radiation Programs, Las Vegas, Nevada, 1977.

EPA83 Environmental Protection Agency, Office of Radiation Programs, Draft Background Information Document, Proposed Standards for Radionuclides, EPA 520/1-83-001, EPA, Office of Radiation Programs, Washington, D.C., March 1983.

EPA84a Environmental Protection Agency, Office of Radiation Programs, Emissions of Lead-210 and Polonium-210 from Calciners at Elemental Phosphorus Plants: FMC Plant, Pocatello, Idaho, EPA, Office of Radiation Programs, Washington, D.C., June 1984.

EPA84b Environmental Protection Agency, Office of Radiation Programs, Emissions of Lead-210 and Polonium-210 from Calciners at Elemental Phosphorus Plants: Stauffer Plant, Silver Bow, Montana, EPA, Office of Radiation Programs, Washington, D.C., August 1984.

EPA84c Environmental Protection Agency, Office of Radiation Programs, Emissions of Lead-210 and Polonium-210 from Calciners at Elemental Phosphorus Plants: Monsanto Plant, Soda Springs, Idaho, EPA, Office of Radiation Programs, Washington, D.C., August 1984.

EPA84d Environmental Protection Agency, Regulatory Impact Analysis of Emission Standards for Elemental Phosphorus Plants, Office of Radiation Programs, Washington, D.C., EPA 520/1-84-025, October 1984.

Ka84 Kalkwarf D.R. and Jackson P.O., Lung-Clearance Classification of Radionuclides in Calcined Phosphate Rock Dust, PNL-5221, Pacific Northwest Laboratories, Richland, Washington, August 1984.

REFERENCES (Continued)

ICRP66	International Radiological Protection Commission Task Group on Lung Dynamics, Deposition and Retention Models for Internal Dosimetry of Human Respiratory Track, Health Phys. 12:173-207, 1966.
MRI84a	Midwest Research Institute, Analysis of Achievable Po-210 Emissions and Associated Costs for FMC's Pocatello, Idaho, Plant, Midwest Research Institute, Raleigh, North Carolina, August 1984.
MRI84b	Midwest Research Institute, Analysis of Achievable Po-210 Emissions and Associated Costs for Monsanto's Soda Springs, Idaho, Plant, Midwest Research Institute, Raleigh, North Carolina, September 1984.
RC84a	Radian Corporation, Emission Testing of Calciner Off-gases at FMC Elemental Phosphorus Plant, Pocatello, Idaho, Volumes I and II, Prepared for U.S. Environmental Protection Agency under Contract No. 68-02-3174, Work Assignment No. 131, Radian Corporation, P.O. Box 13000, Research Triangle Park, NC, 1984.
RC84b	Radian Corporation, Emission Testing of Calciner Off-gases at Stauffer Elemental Phosphorus Plant, Silver Bow, Montana, Volumes I and II, Prepared for U.S. Environmental Protection Agency under Contract No. 68-02-3174, Work Assignment No. 132, Radian Corporation, P.O. Box 13000, Research Triangle Park, NC, 1984.
RC84c	Radian Corporation, Emission Testing of Calciner Off-gases at Monsanto Elemental Phosphorus Plant, Soda Springs, Idaho, Volumes I and II, Prepared for U.S. Environmental Protection Agency under Contract No. 68-02-3174, Work Assignment No. 133, Radian Corporation, P.O. Box 13000, Research Triangle Park, NC, 1984.

Chapter 7: MINERAL EXTRACTION INDUSTRY FACILITIES

Metal Mines, Mills, and Smelters

Almost all industrial operations involving the removal and processing of ores to recover metals release some radionuclides into air. This chapter presents an assessment of the radionuclide emissions from the aluminum, copper, zinc, and lead industries. These industries were studied because they involve the processing of large quantities of ore and because they all involve pyrometallurgical processes which have the greatest potential for radionuclide emissions.

For the aluminum industry the assessment includes emissions from an alumina plant and aluminum reduction plants. The assessments of the copper and zinc industries include assessments of mine, mill, and smelter emissions. Finally, smelter emissions for the lead industry are assessed.

7.1 Aluminum Industry

7.1.1 General Description

Bauxite is the principal aluminum ore found in nature. The ore is processed at the mine to produce alumina (Al_2O_3), the basic feed in the aluminum reduction process. Aluminum metal is produced by the reduction of alumina in a molten bath of cryolite. The production of aluminum differs from other primary metals in that no purification of the metal produced in the electric cells is needed; contaminants in the ore are removed in the milling rather than the smelting phase of the process.

Of the 12 domestic companies producing primary aluminum, only Alcoa and Reynolds perform all stages of production, from domestic mining through the primary metal stage. Almost all of the bauxite used in aluminum production is imported. Five other domestic firms own bauxite and/or alumina facilities in other countries and import raw materials. Only 5 of the 12 firms that own primary aluminum plants also own domestic plants producing the input product, alumina. These five companies (Aluminum Company of America, Kaiser Aluminum and

Table 7.1-1. Location and size of primary aluminum production plants (D0180)

Location	Company	Capacity (1000 MT/y)
Alabama		
Arkadelphia	Reynolds Metals Company	56
Jones Mills	Reynolds Metals Company	103
Listerhill	Reynolds Metals Company	166
Scottsboro	Revere Copper & Brass Co.	95
Indiana		
Evansville	Aluminum Company of America	239
Kentucky		
Hawesville	National Southwire	148
Sebree	Anaconda Aluminum Company	148
Louisiana		
Chalmette	Kaiser Aluminum & Chemical Corp.	215
Lake Charles	Consolidated Aluminum Corporation	30
Maryland		
Frederick	Eastalco Aluminum Company	145
Missouri		
New Madrid	Noranda	115
Montana		
Columbia Falls	Anaconda Aluminum Company	148
North Carolina		
Badin	Aluminum Company of America	103
New York		
Massena	Aluminum Company of America	177
Massena	Reynolds Metals Company	104
Ohio		
Hannibal	Ormet Corporation	215
Oregon		
The Dalles	Martin-Marietta Aluminum Co.	75
Troutdale	Reynolds Metals Company	104
Tennessee		
Alcoa	Aluminum Company of America	182
New Johnsville	Consolidated Aluminum Corporation	119

Table 7.1-1. Location and size of primary aluminum production plants (Continued)

Location	Company	Capacity (1000 MT/y)
Texas		
Point Comfort	Aluminum Company of America	153
Palestine	Aluminum Company of America	13
Rockdale	Aluminum Company of America	268
San Patricio	Reynolds Metals Company	94
Washington		
Ferndale	Intalco Aluminum Corp.	215
Goldendale	Martin-Marietta Aluminum Company	99
Longview	Reynolds Metals Company	174
Mead	Kaiser Aluminum & Chemical Corp.	182
Ravenswood	Kaiser Aluminum & Chemical Corp.	135
Tacoma	Kaiser Aluminum & Chemical Corp.	66
Vancouver	Aluminum Company of America	95
Wenatchee	Aluminum Company of America	173
Total		4354

Chemical Corporation, Reynolds Metals Co., Martin Marietta Aluminum Co., and Ormet Corp.) own 73 percent of the current U.S. primary aluminum capacity (St78).

There are currently 32 operating primary aluminum smelters in the United States (Table 7.1-1). With one exception, all of the plants are located in rural areas. Population densities in the vicinities of the plants range from 12 to 62 persons per square kilometer (EPA79).

7.1.2 Process Description

Bauxite ore is processed at the alumina plant to produce alumina using a modified "American Bayer" process. EPA measurements indicate that the ore is elevated in both uranium-238 and thorium-232 with concentrations of 6.8 and 5.5 pCi/g (EPA82). The data in Table 7.1-2 show that most of the radioactivity in the ore is associated with the impurities rather than the alumina product.

Of the 32 aluminum reduction plants in the United States, all but one produce aluminum in electric furnaces (cells) by the Hall-Hiroult process. In the Hall-Hiroult process, alumina (Al_2O_3) is reduced electrolytically in a molten bath of cryolite ($NaAlF_6$). The Aluminum Company of America's pilot plant in Palestine, Texas, employs aluminum chloride as the electrolyte.

Table 7.1-2. Radionuclide concentrations in alumina plant process samples (EPA82)

Sample	Concentration (pCi/g)	
	Uranium-238	Thorium-232
Bauxite ore	6.8	5.5
Alumina kiln feed	0.05	0.05
Alumina product	0.28	0.2
Red mud	7.5	5.0
Brown mud	5.5	12.5

Two basic types of cells are used by the industry: prebake and Soderberg. The chief difference between the two types is the means by which carbon is supplied to the reduction cells. At prebake plants, both center- and side-worked cells use preformed carbon anodes baked into a solid mass. Soderberg cells use carbon anode paste which is fed to the cell continuously.

Both types of reduction cells are operated at temperatures in excess of 950° C, the melting point of the cryolite. Approximately 2.6 metric tons of raw materials, along with large quantities of electricity, are required to produce 1 MT of aluminum. The breakdown of raw materials is shown in Table 7.1-3.

Table 7.1-3. Raw materials used in producing aluminum (EPA77)

Raw material	MT Feed/MT Al produced
Alumina (Al_2O_3)	1.9
Cryolite ($NaAlF_6$)	0.03-0.05
Aluminum Fluoride (AlF_3)	0.03-0.05
Fluorspar (CaF_2)	0.003
Petroleum Coke	0.455-0.490
Pitch Binder	0.123-0.167
Carbon (cathode)	0.02

The particulate emissions from the process reflect the composition of the feed materials, and include alumina, carbon, cryolite, aluminum fluoride, and trace elements. Generation of particulate emissions varies with the type of cells. At prebake plants, particulate emissions from the anode furnace range from 0.5 to 2.5 kg/MT of aluminum produced, with 1.5 kg/MT being a typical value (EPA76). Particulate emissions generated by the cells vary from 5.95 to 88.5 kg/MT, with 40.65 kg/MT being typical (EPA76).

Quality of Feed Materials

No evidence could be found that the quality of feed materials varies to any significant degree. Radionuclide concentrations for input materials are given in Table 7.1-4.

Table 7.1-4. Radionuclide concentrations of feed materials to aluminum plants (EPA82)

Feed material	Radionuclide concentration (pCi/g)	
	Uranium-238	Thorium-232
Alumina	0.10	<0.2
Aluminum Fluoride	0.11	<0.2
Cryolite	0.11	<0.2

7.1.3 Control Technology for Primary Aluminum Reduction Plants

Controls for emissions from aluminum plants are either primary or secondary controls. Primary controls handle the emissions captured by the cell hoods, while secondary controls are used to treat the entire building effluent, including cell emissions that escape the primary hoods. Primary controls are used at all plants, but secondary controls are generally used only by the plants that employ Soderberg cells (EPA79).

Control devices used for primary control vary widely from plant to plant, and include multicyclones, dry and fluid bed alumina adsorbers followed by fabric filters or electrostatic precipitators, and spray towers with spray screens. Not only do the efficiencies of these devices vary over a considerable range (70 to 99+ percent), but the collecting hoods for the various types of cells range from less than 80 percent to greater than 95 percent capture efficiency (EPA79).

7.1.4 Radionuclide Emissions

Emissions from the alumina kilns and red mud kilns at an alumina plant are given in Table 7.1-5. The low radioactivity of alumina is reflected in the low radionuclide emissions from the alumina kilns. Emissions of radionuclides from the red mud sinter kiln were below measurable concentrations except for lead-210, polonium-210, and radon-222. The high temperature of the kiln causes a large fraction of lead-210 and polonium-210 to be volatilized.

Table 7.1-5. Radionuclide emissions from the surveyed alumina plant (EPA82)

Radionuclide	Emissions (Ci/y)	
	Alumina kilns	Red mud kilns
Uranium-238	8.7E-3	
Uranium-234	5.7E-3	
Radium-226	2.7E-3	
Radon-222		2.75
Lead-210		4.8E-2
Polonium-210		4.0E-2

Particulate material emitted from an aluminum reduction plant contains radionuclide concentrations (pCi/g) similar to or greater than the concentrations in the alumina processed. Because of the high temperatures of the reduction cells, lead-210 and polonium-210 are volatilized and released in greater quantities than the other radionuclides in the alumina. EPA has measured the radionuclide emissions from an aluminum reduction plant. The emission estimates for the reference aluminum reduction plant are based on data from these measurements.

7.1.5 Reference Facilities

Measured emissions from a single alumina plant were used to estimate health impacts for alumina production.

Table 7.1-6 describes the parameters of a reference aluminum reduction plant which are used to calculate the radionuclide emissions to air and the resulting health impacts and to give a general idea of plant parameters.

Since the currently operating facilities have similar particulate emission rates and use roughly the same process and feed stocks, one reference plant characterizes the primary aluminum source category. It uses center-worked prebake cells, the most commonly used equipment now in operation. The capacity chosen (136,000 metric tons/y of aluminum) is approximately the average size of all existing plants. A capacity factor of 0.94 is applied to the plant, the 1979 industry-wide average (DOI80).

Table 7.1-6. Reference aluminum reduction plant

Parameter	Value
Capacity	136,000 MT/y aluminum
Capacity factor	0.94
Type of equipment	Center-worked prebake cells
Stack Parameters	
Main stack	
Height	36 m (4 stacks)
Diameter	3 m
Exit gas velocity	80 m/s
Exit gas temperature	160° C
Roof monitor	
Height	10 m
Diameter	1.2 m
Exit gas velocity	0.01 m/s
Exit gas temperature	37° C
Anode bake plant	
Height	30 m
Diameter	1.8 m
Exit gas velocity	4.5 m/s
Exit gas temperature	96° C

As of 1975, 95 percent of all plants had at least primary control of particulate emissions, and 73 percent were reported to have "best" primary control; only 11 percent had "best" primary plus secondary control (EPA79). It is presumed that "best" primary control consists of the best available hooding, plus a fluidized-bed scrubber since this unit can achieve the highest reported control efficiencies (97-99 percent removal). Based on this information, the reference plant is equipped with a fluidized-bed scrubber for primary control. The plant has no secondary control equipment. As for the anode bake plant, a spray scrubber constitutes the particulate control system.

Radionuclide emissions for the reference plant were based on actual measurements of radionuclide concentrations in the particulate emissions from an existing plant. The resulting releases are listed in Table 7.1-7.

Table 7.1-7. Radionuclide emissions from the reference aluminum reduction plant

Radionuclide	Emissions (Ci/y)		
	Main stack[(a)]	Roof monitor	Anode bake plant
Uranium-238	6.8E-5	8.1E-9	8.0E-5
Uranium-234	6.8E-5	8.1E-9	8.0E-5
Thorium-230	2.4E-4	3.8E-8	4.0E-5
Radium-226	5.5E-5	7.4E-9	6.0E-5
Lead-210	3.2E-4	2.0E-7	2.0E-4
Polonium-210	2.7E-4	2.0E-7	2.0E-4
Thorium-232	--	2.9E-8	3.2E-5
Radium-228	--	2.9E-8	3.2E-5

(a) Only main stack emissions were used to calculate doses from aluminum reduction plant.

7.1.6 Health Impact Assessment

The estimated annual radiation doses and health risks from the emissions from the alumina plant are given in Tables 7.1-8 through 7.1-10. These estimates are for a rural site with a regional population of 6E+5.

Table 7.1-8. Radiation dose rates from radioactive particulate emissions from the surveyed alumina plant

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Lung	1.7E-2	15.8
Red marrow	0.2	2.63
Endosteum	2.0	38.0
Breast	7.5E-2	0.26
Liver	4.6E-1	1.35

Table 7.1-9. Annual radon decay product exposures from radon-222 emissions from the surveyed alumina plant

Source	Nearby individuals (WL-y)	Regional population (person-WL-y)
Stack	8.5E-10	8E-4

Table 7.1-10. Fatal cancer risks from radionuclide emissions from the surveyed alumina plant

Source	Lifetime risk to nearby individuals		Regional population (Fatal cancers/y of operation)	
Particulates	1E-6		4E-4	
Radon-222	9E-10(a)	4E-10(b)	1E-5(a)	8E-6(b)
Total	1E-6		4E-4(a)	4E-4(b)

(a)Based on BEIR-3, NRPB, and EPA models (see Chapter 8, Volume I).
(b)Based on USCEAR and ICRP risk estimates (see Chapter 8, Volume I).

The estimated annual radiation doses from radionuclide emissions from the reference aluminum reduction plant are listed in Table 7.1-11. These estimates are for a rural site with a regional population of 2.7E+5.

Table 7.1-12 presents estimates of the lifetime risk to nearby individuals and number of fatal cancers per year of operation from these doses.

Table 7.1-11. Radiation dose rates from radionuclide emissions from the reference aluminum reduction plant

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Lung	7.2E-4	1.29
Red marrow	0.1	.35
Endosteum	5.3E-1	1.63
Breast	6.9E-2	.23
Liver	3.7E-1	1.10
Kidney	1.2	4.06

Table 7.1-12. Fatal cancer risks due to radionuclide emissions from the reference aluminum reduction plant

Source	Lifetime risk to nearby individuals	Regional population (Fatal cancers/y of operation)
Aluminum reduction plant (particulates)	8E-7	7E-5

7.1.7 Existing Emission Standards and Air Pollution Controls

No Federal or state regulations currently exist that limit radionuclide emissions from alumina plants or aluminum reduction plants. Particulate emissions from these sources are limited to the quantities established by the states in their State Implementation Plans (SIPs) for meeting Ambient Air Quality Standards.

Several states have established specific SIP limits for aluminum reduction plants, ranging from 15 to 20 lbs/ton of aluminum produced. In states where no specific limits have been established for aluminum, emissions from these sources are regulated according to the limits established in the SIPs for general processing sources.

REFERENCES

DOI80 U.S. Department of the Interior, 1980, Mineral Commodity Summaries, Bureau of Mines, January 1980.

EPA76 Environmental Protection Agency, Compilation of Air Pollution Emission Factors, Second Ed., Part B, AP-42, Feburary 1976.

EPA77 Environmental Protection Agency, Technical Guidance for Control of Industrial Process Fugitive Particulate Emissions, EPA-450/3-77-010, March 1977.

EPA79 Environmental Protection Agency, Primary Aluminum: Draft Guidelines for Control of Fluoride Emissions from Existing Primary Aluminum Plants, EPA-450/2-78-049, February 1979.

EPA82 Environmental Protection Agency, Emissions of Naturally Occurring Radioactivity from Aluminum and Copper Facilities, EPA 520/6-82-018, Las Vegas, Nevada, November 1982.

St78 Stamper J. W. and Kurtz H. F., Mineral Commodity Profile-Aluminum, U.S. Department of the Interior, Bureau of Mines, Washington, D.C.

7.2 Copper Industry

7.2.1 General Description

Copper ores are milled to produce a concentrate containing copper, sulfur, iron, and some insoluble material (primarily silica and aluminum). This concentrate is the basic feed to the copper smelter that eventually produces the refined copper product. Copper mills and smelters are located near copper mines. Copper concentrates and precipitates are generally smelted by melting the charge and suitable fluxes in a reverberatory furnace. Prior to smelting, part or all of the concentrates may receive a partial roast to eliminate some of the sulfur and other impurities.

The 15 operating primary copper smelters in the United States and their capacities are listed in Table 7.2-1. Total production of primary copper in 1978 was 1.5 million metric tons (Sc79).

All primary copper smelters are located in rural areas with low population densities. Ninety percent of U.S. copper smelter capacity is located in the arid and semi-arid climates of Arizona, Montana, Nevada, New Mexico, Texas, and Utah. The other 10 percent are in Washington, Michigan, and Tennessee, areas of moderate to high precipitation. The sites tend to be quite large and generally contain associated mining and milling operations.

Most companies perform all production processes from mining through refining. Seven of the eight companies that own smelters also operate mines and own refineries; Cities Services, which owns the smallest of the smelters, is the only exception (Sc79).

7.2.2 Process Description

The three major steps in the smelting of copper are roasting, smelting, and converting. All of these processes result in releases of sulfur dioxide and particulate matter in process off-gas. Each step in the smelting process is described below.

Roasting

Roasting is the first step in the process of copper smelting. In the roaster, copper ore concentrates are heated to a high temperature (550° C) in an oxidizing atmosphere which partially drives off some of the sulfur as sulfur dioxide (in addition to producing particulate emissions). Seven of the fifteen domestic copper smelters have roasters; four plants feed ore concentrates to a rotary dryer to reduce moisture before smelting; and three feed concentrates directly to the furnace with no pretreatment.

Table 7.2-1. Primary Copper Smelters in the United States, 1978 (Sc79)

Plant location	Company	Capacity (1000 MT)	First year of operation
Arizona			
Hayden	ASARCO, Inc.	163	1890
Miami	Inspiration Consolidated	136	1951[a]
Hayden	Kennecott Copper Corp.	73	1958
San Manuel	Magma Copper Company	181	1950
Morenci	Phelps Dodge Corporation	161	1942
Douglas	Phelps Dodge Corporation	115	1910
Ajo	Phelps Dodge Corporation	63	1950
Michigan			
White Pine	Copper Range Company	82	1905
New Mexico			
Hurley	Kennecott Copper Corp.	73	1939
New Mexico			
Hidalgo	Phelps Dodge Corporation	127	1976
New York			
McGill	Kennecott Copper Corp.	45	1907
Tennessee			
Copper Hill	Cities Services Company	20	1845
Texas			
El Paso	ASARCO, Inc.	104	1905
Utah			
Garfield	Kennecott Copper Corp.	254	1907
Washington			
Tacoma	ASARCO, Inc.	91	1890
Total		1688	

(a)Rebuilt as of 1979.

Smelting

All domestic copper smelters use smelting furnaces to melt and react copper concentrate and/or calcine in the presence of silica and limestone flux to form two immiscible liquid layers, one being the slag or waste layer containing most of the iron and silica compounds and the other containing copper and iron sulfide and other metals, referred to as matte copper. Smelting is conducted in either reverberatory or electric furnaces. Reverberatory furnaces are refractory-lined, box-shaped structures heated by either natural gas, oil, or coal. Reverberatory smelting furnaces are more common than electric furnaces. Currently, 2 out of 15 smelters use electric furnaces to smelt copper. Electric furnaces have basically the same construction as reverberatory furnaces.

Converting

The converter processes matte copper from the reverberatory furnace by removing iron compounds and converting to copper at high temperatures (550 to 800° C). The resulting blister copper is further purified by processing in a refining furnace and by electrolytic refining.

7.2.3 Control Technology

Of the 15 primary copper smelters currently operating, 11 use reverberatory furnaces and 7 have roasters. Of these 7, 4 use multi-hearth roasters while the other 3 use fluid-bed roasters. The actual smelting process used by those plants with reverberatory furnaces does not differ from facility to facility. Acid gas cleanup plants have been installed on all but three currently operating smelters to treat converter off-gases. A cyclone, a water spray chamber, and an electrostatic precipitator (ESP) are used to clean these gases prior to their entering the SO_2 plant. Off-gases from the reverberatory furnace are controlled via an ESP in virtually all of the operating plants. Three of the four multi-hearth roasters currently operating treat their roaster off-gases by using ESPs.

7.2.4 Radionuclide Emission Measurements

EPA has recently carried out radionuclide measurement studies at both an underground copper mine and mill and an open pit copper mine and mill (EPA82). The results of these studies indicate that radon-222 is the only significant radionuclide emitted from the underground mine. At the open pit mine and mill, radioactive particulates and radon-222 are emitted, primarily during truck loading and dumping and crushing operations.

The measurement studies also included analysis of radioactivity in various process samples. Table 7.2-2 lists the uranium-238 and thorium-232 concentrations in process samples from both the underground mine and mill and the open pit mine and mill.

Table 7.2-2. Radionuclide concentrations in surveyed copper mine and mill process samples (EPA82)

Type of sample	Underground mine and mill		Open pit mine and mill	
	Uranium-238 (pCi/g)	Thorium-232 (pCi/g)	Uranium-238 (pCi/g)	Thorium-232 (pCi/g)
Ore	0.79	0.62	2.2	3.1
Concentrate	0.65	0.07	1.4	1.1

Particulate material emitted from a copper smelter contains radionuclides in concentrations (pCi/g) similar to or greater than the ore concentrates. Because of the high temperatures of the roasting and smelting, some radionuclides (particularly lead-210 and polonium-210) may be volatilized and released in greater quantities than the other radionuclides in the ore concentrates.

Very little information has been available to date on radionuclide emissions from copper smelters. EPA has recently surveyed two copper smelters, and the data from these studies were used in estimating radionuclide emissions from the reference copper smelter.

7.2.5 Reference Facilities

Actual emissions data from EPA's measurement studies were used to assess potential health impacts from the underground mine (Table 7.2-3) and open pit mine and milling complexes (Table 7.2-4).

Table 7.2-3. Radionuclide emissions from the underground copper mine (EPA82)

Radionuclide	Emissions (Ci/y)
Radon-222	6.5

Table 7.2-5 describes the parameters of a reference copper smelter which were used to estimate the radioactive emissions to the atmosphere and the resulting health impacts. The capacity of the plant is 56,000 MT/y of copper, the average size of all existing plants without roasters. The capacity factor chosen for this plant is 0.75. Main stack heights for facilities without roasters range from 61 to 228 meters. The control equipment applied to the reference facility was chosen to represent typical equipment on actual copper smelters.

Table 7.2-4. Radionuclide emissions from copper mill, open pit mine, and concentrator (EPA82)

Radionuclide	Emissions (Ci/y)
Uranium-238	3.1E-4
Uranium-234	3.8E-4
Radium-226	1.8E-4
Radon-222	1.9
Lead-210	1.9E-3

Total annual emissions of radionuclides from the reference copper smelter are given in Table 7.2-6. These values were derived from data on radionuclide releases from an existing plant. Reported release rates were adjusted to account for differences between the actual and reference facility in annual particulate emissions and total capacity.

Table 7.2-5. Reference copper smelter

Parameter	Value
Capacity	56,000 MT/y
Capacity factor	0.75
Type of equipment used	Reverberatory furnace
Stack Parameters	
Main stack	
Height	183 m
Diameter	2.6 m
Exhaust gas velocity	28 m/s
Exhaust gas temperature	135° C
Acid plant	
Height	30.4 m
Diameter	1.8 m
Exhaust gas velocity	16.5 m/s
Exhaust gas temperature	79° C
Particulate Emission Rate	
Main stack	247 kg/h
Acid plant	11 kg/h

Table 7.2-6. Radionuclide emissions from the reference copper smelter (southwestern site)

Radionuclide	Emissions (Ci/y)
Uranium-238	4.0E-2
Uranium-234	4.0E-2
Thorium-230	2.1E-3
Radium-226	1.5E-3
Lead-210	6.5E-2
Polonium-210	3.0E-2
Thorium-232	1.2E-3
Thorium-228	1.3E-3

7.2.6 Health Impact Assessment

The estimated radiation doses from radionuclide emissions from the underground mine and mill, the open pit mine and mill, and the reference copper smelter are listed in Tables 7.2-7 through 7.2-10. These estimates are for a low population density southwestern site with a regional population of 3.6E+4.

Table 7.2-11 presents estimates of the lifetime risk to nearby individuals and number of fatal cancers per year of operation resulting from these doses.

Table 7.2-7. Annual radon decay product exposures from radon-222 emissions from the underground copper mine(a)

Source	Nearby individuals (WL-y)	Regional population (person-WL-y)
Mine vent	2.5E-5	4.2E-4

(a)Based on a ground level release.

Table 7.2-8. Radiation dose rates from radioactive particulate emissions from the open pit copper mine and mill[a]

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Lung	1.1E+1	2.1E-1
Red marrow	1.6	2.8E-2
Endosteum	2.5E+1	4.5E-1
Breast	2.2E-2	4.2E-4
Liver	9.9E-2	1.8E-3

[a] Based on a 10-meter stack height.

Table 7.2-9. Annual radon decay product exposures from radon-222 emissions from the open pit copper mine and mill

Source	Nearby individuals (WL-y)	Regional population (person-WL-y)
Stack	7.2E-6	1.2E-4

Table 7.2-10. Radiation dose rates from radionuclide particulate emissions from the reference copper smelter (southwestern site)

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Lung	2.0E-1	0.95
Red marrow	3.2E-3	1.4E-2
Endosteum	4.5E-2	0.21
Breast	2.9E-4	1.2E-3
Liver	2.2E-3	8.7E-3

Table 7.2-11. Fatal cancer risks from radionuclide emissions from the underground copper mine, the open pit copper mine and mill, and the reference copper smelter

Source	Lifetime risk to nearby individuals		Regional population (Fatal cancers/y of operation)	
		Underground copper mine		
Particulates	1E-7		4E-8	
Radon-222	4E-5(a)	2E-5(b)	8E-6(a)	4E-6(b)
Total	4E-5(a)	2E-5(b)	8E-6(a)	4E-6(b)
		Open pit copper mine and mill		
Particulates	2E-5		5E-4	
Radon-222	9E-6(a)	4E-7(b)	3E-6(a)	1E-6(b)
Total	3E-5(a)	2E-5(b)	5E-4(a)	5E-4(b)
		Reference copper smelter		
Particulates	3E-7		2E-5	

(a) Based on BEIR-3, NRPB, and EPA models (see Chapter 8, Volume I).
(b) Based on USCEAR and ICRP risk estimates (see Chapter 8, Volume I).

7.2.7 Existing Emission Regulations and Air Pollution Controls

No Federal or state regulations currently exist that limit radionuclide emissions from copper processing operations. Particulate emissions from these sources are regulated by New Source Performance Standards (NSPS) for plants constructed after October 1974, or by limits established by the states in their State Implementation Plans (SIPs) for Ambient Air Quality Standards. Several of the states where copper smelters are located have adopted specific emission limits for different smelting operations, while other states regulate these sources under the general processing category limits established in their SIPs.

REFERENCES

EPA82 Environmental Protection Agency, Emissions of Naturally Occurring Radioactivity from Aluminum and Copper Facilities, EPA 520/6-82-018, Las Vegas, Nevada, November 1982.

Sc79 Schroeder H. J., Mineral Commodity Profiles--Copper, U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 1979.

7.3 Zinc Industry

7.3.1 General Description

Zinc is usually found in nature as a sulfide ore called sphalerite. The ores, which usually contain impurities of lead, cadmium, and traces of other elements, are processed at the mine to form concentrates typically containing 62 percent zinc and 32 percent sulfur. These concentrates are processed at the smelter to recover zinc metal.

The five operating primary zinc production facilities in the United States and their capacities are listed in Table 7.3-1. Total production capacity for primary zinc in 1980 was 401,000 metric tons. The domestic demand for zinc is expected to grow at a rate of about 2 percent per year through 1985 (Ca78).

In the past 10 years, U.S. demand for zinc metal has grown slowly, but U.S. smelting capacity has declined by over 50 percent. Plants closed because they were obsolete, could not meet environmental standards, or could not obtain sufficient concentrate feed. Consequently, the metal has replaced concentrate as the major form of import. This situation is expected to continue.

7.3.2 Process Description

A zinc smelter produces 99.99+ percent zinc from the approximately 62 percent zinc concentrate feed produced by the mill. The zinc concentrates are roasted at approximately 600° C to convert sulfur to sulfur dioxide and to produce an impure zinc oxide or calcine. The calcine is transferred to tanks, leached with dilute sulfuric acid, and treated with a small amount of zinc oxide dust to remove impurities, such as lead, gold, and silver.

The leaching step varies somewhat from plant to plant, but the basic process of selective precipitation of the impurities from the leach solution remains the same. This solution is purified and piped to electrolytic cells, where the zinc is electro-deposited on aluminum cathodes. Domestic zinc smelters use electrolytic reduction to reduce the quantity of sulfur and particulate emissions.

The cathodes are lifted from the tanks at intervals and stripped of the zinc, which is melted in a furnace and cast into slabs. Electrolysis of the solution regenerates sulfuric acid which is used in succeeding cycles of leaching.

7.3.3 Control Technology

Ore concentrates are heated in roasters to temperatures ranging from 500° C to 700° C to remove most of the sulfur in the sulfide

Table 7.3-1. Location and size of primary zinc production plants[a] (Ca78)

Location	Company	First year of operation	Capacity (Thousands of MT)
Idaho			
Kellogg[b]	Bunker Hill	1928	95
Illinois			
Sauget	AMAX	Rebuilt in 1970's	76
Oklahoma			
Bartlesville	National	1976	51
Tennessee			
Clarksville	Jersey Miniere	1978	81
Texas			
Corpus Christi	Asarco	1942	98
Total			401

(a)All plants use the electrolytic process.
(b)Plant is now shut down.

ore and to form calcine. Roaster off-gases containing sulfur dioxide are treated in single or double contact acid plants. The off-gas also contains significant amounts of calcine, which is recovered in waste heat boilers, cyclones, and ESP's and then recycled. In addition, most acid plants have wet scrubbers, wet ESP's, and demisting towers before the plant catalyst to remove residual particulate matter which could foul the catalyst bed.

The electrolytic (or hydrometallurgical) zinc smelting process is a minor source of particulate emissions, and is not serviced by a particulate control device.

7.3.4 Radionuclide Emissions

Measurements of radionuclide emissions from an underground zinc mine and a zinc mill show radon-222 to be the principal radionuclide emitted to air. Uranium-238 and thorium-232 and their decay products are released in much smaller quantities. Annual source terms for the zinc mine and mill are listed in Table 7.3-2.

Table 7.3-2. Radionuclide emissions from the zinc mine and mill (EPA82)

Radionuclide	Emissions (Ci/y)
Uranium-238	1.8E-3
Uranium-234	1.8E-3
Thorium-230	1.5E-3
Radium-226	8.2E-4
Radon-222	2.3E+2
Lead-210	2.6E-3
Polonium-210	2.2E-3
Thorium-232	6.0E-4
Thorium-228	4.7E-4

Particulate material emitted from a zinc smelter contains radionuclides in concentrations similar to or greater than the concentrations in the materials processed. Because of the high temperatures to which the concentrates are heated, some of the radionuclides (particularly lead-210 and polonium-210) may be volatilized and released in greater quantities than the other radionuclides in the ore concentrates.

7.3.5 Reference Facilities

Actual emissions from a mine and mill complex (chosen because of the high working level measurements reported for the mine, and high production rates) were used to estimate health impacts from these sources.

Table 7.3-3 describes the parameters of a reference zinc smelter which were used to estimate the radioactive emissions to the atmosphere and the resulting health impacts.

The reference zinc smelter has a total production capacity of about 88,000 MT/y, typical of the industry. The plant produces zinc by electrolytic reduction and operates at an annual capacity factor of 0.80, the 1976 industry-wide average (DO176). The flow rate was derived by adjusting available data for differences in capacity and capacity factor. The stack height and diameter were estimated from available data.

Roaster off-gases are treated for dust removal by a cyclone in series with an electrostatic precipitator. The cleaned gases are then passed through a sulfur dioxide (SO_2) plant. Off-gases from the electrolytic reduction step are vented directly to the atmosphere.

The total annual radionuclide emissions for the reference zinc smelter are listed in Table 7.3-4.

Table 7.3-3. Reference zinc smelter

Parameter	Value
Process	Electrolytic reduction
Capacity	88 E+3 MT/yr zinc
Capacity factor	0.8
Radionuclide concentration of input ore[a]	
Uranium-238	0.18 pCi/g
Thorium-232	0.08 pCi/g
Stack Parameters	
Number	1
Height	100 meters
Diameter	2 meters
Exhaust gas velocity	20 m/s
Exhaust gas temperature	150° C

[a] Recent measurements by EPA (EPA82) at a zinc smelter.

Table 7.3-4. Radionuclide emissions from the reference zinc smelter

Radionuclide	Emissions (Ci/y)
Uranium-238	5.6E-4
Uranium-234	3.7E-4
Thorium-230	1.4E-3
Radium-226	4.5E-3
Radon-222	2.8E-1
Lead-210	2.5E-2
Polonium-210	1.5E-3
Thorium-232	3.4E-4
Thorium-228	3.4E-4

7.3.6. Health Impact Assessment

The estimated annual radiation doses from the radionuclide emissions of the zinc mine, mill, and smelter are listed in Tables 7.3-5 through 7.3-8. These estimates are for a rural site with a regional population of 6E+5. The lifetime risk to nearby individuals and number of fatal cancers per year of operation are shown in Tables 7.3-9 and 7.3-10.

Table 7.3-5. Radiation dose rates from radioactive particulate emissions from the zinc mine and mill(a)

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Lung	4.1	14.1
Red marrow	3.6E-1	1.27
Endosteum	5.8	20.1
Breast	4.7E-3	1.8E-2
Liver	2.1E-2	8.1E-2

(a)Based on Arkansas population.

Table 7.3-6. Annual radon decay product exposures from radon-222 emissions from the zinc mine and mill(a)

Source	Nearby individuals (WL-y)	Regional population (person-WL-y)
Mine vent	1E-4	4E-1

(a)Based on Arkansas population.

Table 7.3-7. Annual radon decay product exposures from radon-222 emissions from the zinc smelter

Source	Nearby individuals (WL-y)	Regional population (person-WL-y)
Zinc smelter	5.3E-10	6E-5

Table 7.3-8. Radiation dose rates from radionuclide emissions from the reference zinc smelter(a)

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Lung	1.0E-2	1.12
Red marrow	1.7E-3	2.0E-1
Endosteum	2.2E-2	2.5
Breast	2.4E-4	2.7E-2
Liver	1.4E-3	1.6E-1

(a)Based on Arkansas population.

Table 7.3-9. Fatal cancer risks from radionuclide emissions from the zinc mine and mill(a)

Source	Lifetime risk to nearby individuals		Regional population (Fatal cancers/y of operation)	
Particulates	7E-6		3E-4	
Radon-222	2E-4(b)	8E-5(c)	8E-3(b)	4E-3(c)
Total	2E-4(b)	9E-5(c)	9E-3(b)	4E-3(c)

(a)Based on Arkansas population.
(b)Based on BEIR-3, NRPB, and EPA models (see Chapter 8, Volume I).
(c)Based on USCEAR and ICRP risk estimates (see Chapter 8, Volume I).

Table 7.3-10. Fatal cancer risks from radionuclide emissions from the reference zinc smelter(a)

Source	Lifetime risk to nearby individuals		Regional population (Fatal cancers/y of operation)	
Particulates	2E-8		4E-5	
Radon-222	7E-10(b)	3E-10(c)	1E-6(b)	6E-7(c)
Total	2E-8(b,c)		4E-5(b,c)	

(a)Based on Arkansas population.
(b)Based on BEIR-3, NRPB, and EPA models (see Chapter 8, Volume I).
(c)Based on USCEAR and ICRP risk estimates (see Chapter 8, Volume I).

7.3.7 Existing Emission Standards and Air Pollution Controls

No Federal or state regulations currently exist that limit radionuclide emissions from zinc smelting. Particulate emissions from zinc smelting are regulated by New Source Performance Standards (NSPS) for plants built after October 1974, or by the limits established in State Implementation Plans (SIPs) for meeting Ambient Air Quality Standards. The NSPS for zinc smelting is less than 50 mg/Dry Standard Cubic Meters.

REFERENCES

Ca78 Cammarota V. A., Jr., Mineral Commodity Profiles-Zinc, MCP-12, U.S. Department of the Interior, Bureau of Mines, May 1978.

DOI76 Department of Interior, Preprint from the 1976 Bureau of Mines Minerals Yearbook: Zinc, Washington, D.C., 1976.

EPA82 Environmental Protection Agency, Emissions of Naturally Occurring Radioactivity: Underground Zinc Mine and Mill, EPA 520/6-82-020, Las Vegas, Nevada, November 1982.

7.4 Lead Industry

7.4.1 General Description

Galena (PbS), frequently containing cerussite ($PbCO_3$) and anglesite ($PbSO_4$), is the principal lead-bearing ore found in nature. A sulfide ore, galena contains small amounts of copper, iron, zinc, and other trace elements (EPA75). In the smelting process, lead bullion (95-99 percent lead metal) is separated from ore concentrates (45-80 percent lead).

Table 7.4-1 lists the location and size of the primary lead smelters. Three facilities have integrated smelter/refinery complexes and two facilities (ASARCO's El Paso and East Helena smelters) ship their drossed lead bullion to the company's Omaha refinery for final processing. Refinery operations, including those co-located with smelters, are not considered part of the primary lead source category.

Three of the smelters are located in southeastern Missouri and process only ores from the Missouri lead belt. The smelters located in Texas and Montana are custom smelters, designed to handle larger variations in ore composition than the Missouri smelters. Both domestic and foreign ores are smelted at the western plants.

The design capacities of the primary lead smelters, expressed as annual lead metal output, range from 82,000 to 204,000 tons. Total production from primary smelters in 1979 was 594,000 tons (DOC80).

7.4.2 Process Description

Lead smelting involves three distinct processes: sintering, to convert the ore from a sulfide to an oxide or sulfate form and prepare the feed materials for furnacing; furnacing, to reduce the oxide feed to lead metal; and drossing, to reduce the copper content of the lead bullion from the furnace. After drossing, additional refining steps, as dictated by the specific impurities present and the intended end-use of the product, are performed to yield the purified lead metal.

7.4.3 Control Technology

Off-gases from the sintering machine and the blast furnace are the most significant sources of particulate emissions from the lead smelting process; together these two sources account for more than 95 percent of particulate emissions.

Sintering Machines

Particle size distribution of particulate matter entrained in off-gas from sintering machines indicated that the majority of particles are less than 10 microns in diameter. This relatively small particle size precludes the use of mechanical collectors or wet

Table 7.4-1. Location and size of primary lead production plants (DO177)

Location	Company	First year of operation	Capacity (Thousands of tons of Pb)
Idaho			
Kellogg[a]	Bunker Hill	1917	117
Missouri			
Boss	Amax-Homestake	1968	127
Glover	ASARCO	1968	100
Herculanium	St. Joe Minerals	1892 rebuilt 1970's	220
Montana			
East Helena	ASARCO	1888	82
Texas			
El Paso	ASARCO	1887	82

(a) Now shut down.

scrubbing systems, which decrease in efficiency substantially with decreasing size of the particle collected. Consequently, five of the six existing lead sintering machines use fabric filters for particulate emission control; the sixth employs an ESP (IERL79). The final control devices, in many cases, are preceded by ballon flues or settling chambers for gravitational collection of more massive particles before off-gases enter the ESP or fabric filter.

Sinter off-gas is typically fed to an acid plant for recovery of sulfur dioxide after particulate cleaning, as described above. Efficient operation of the acid plant requires gases containing 5 percent or more SO_2. The circuit of gases through the sinter machine may be quite complex with weak (in SO_2) gases being recirculated through an upstream section of the machine to enrich the SO_2 content before going to the acid plant.

Blast Furnaces

The majority of particles in the lead blast furnace off-gas are smaller than 10 microns in diameter. Consequently, all blast furnace systems currently in operation are serviced by baghouses. The particulate collection efficiencies of baghouses treating lead blast furnace off-gas is roughly 99 percent.

7.4.4 Radionuclide Emissions

Particulate material emitted from a lead smelter contains radionuclides in concentrations similar to or greater than the concentrations in the materials processed. Since enrichment takes place when nuclides volatilize during the high-temperature phase of production, the concentration of some radionuclides will be higher in the particulates than in the original ore. EPA has recently measured the radionuclide emissions at a lead smelter, and results of these measurements are used in this report. Radionuclide emissions are presented in Table 7.4-3.

7.4.5 Reference Facility

Table 7.4-2 describes the parameters of the reference facility which were used to describe the radioactive emissions to the atmosphere and the resulting health impacts.

The reference lead smelter has a capacity of 220,000 MT lead per year, typical of existing plants. The plant operates at a load factor of 0.92 which was the industry-wide average for 1979 (DOC80). There are two stacks at the plant--a main stack and an acid plant tail gas stack. For calculational purposes, however, emissions were treated as coming from one stack.

7.4.6 Health Impact Assessment of Reférence Smelter

The estimated radiation doses from radionuclide emissions from the reference lead smelter are listed in Table 7.4-4. These estimates are for a rural site with a regional population of 2.9E+5.

Table 7.4-5 presents estimates of the maximum individual lifetime risk and number of fatal cancers per year of operation of the reference smelter.

7.4.7 Existing Emission Standards and Air Pollution Controls

No Federal or state regulations currently exist that limit radionuclide emissions from lead smelting. Particulate emissions from lead smelters are regulated by New Source Performance Standards (NSPS) for plants built after October 1974, or by State Implementation Plans (SIPs). The NSPS for lead sintering machines, blast furnaces, and dross furnaces is less than 50 mg/Dry Standard Cubic Meters.

Table 7.4-2. Reference lead smelter

Parameter	Value
Capacity	2.2E+5 MT/yr lead
Capacity factor	0.92
Radionuclide concentration of input ore:	
Uranium-238	0.9 pCi/g
Thorium-232	0.5 pCi/g
Stack Parameters	
Number	1
Main stack	
Height	30 meters
Diameter	1 meter
Exit gas velocity	9 m/s
Exhaust gas temperature	90°C
Acid plant stack	
Height	30 meters
Diameter	1.8 meters
Exhaust gas velocity	1.7 m/s
Exhaust gas temperature	93°C

Table 7.4-3. Radionuclide emissions from the reference lead plant

Radionuclide	Emissions[a] (Ci/y)
Uranium-238	8.6E-3
Uranium-234	8.6E-3
Thorium-230	7.3E-4
Radium-226	5.9E-4
Lead-210	2.6E-2
Polonium-210	2.1E-2
Thorium-232	7.0E-4
Thorium-228	7.0E-4

[a] Main stack only.

Table 7.4-4. Radiation dose rates from radionuclide emissions from the reference lead smelter

Organ	Nearby individuals (mrem/y)	Regional population (person-rem/y)
Lung	4.8	6.9E+1
Red marrow	1.2E-1	1.8
Endosteum	1.8	2.6E+1
Breast	9.9E-3	0.17
Liver	5.9E-2	1.01

Table 7.4-5. Fatal cancer risks due to radionuclide emissions from the reference lead smelter

Source	Lifetime risk to nearby individuals	Regional population (Fatal cancers/y of operation)
Particulates	8E-6	1.6E-3

REFERENCES

DOC80 U.S. Department of Commerce, U.S. Industrial Outlook for 200 Industries with Projections for 1984, Washington, D.C., 1980.

DOI77 U.S. Department of the Interior, Lead Mineral Commodity Profiles--Lead, Washington, D.C., December 1977.

EPA75 Environmental Protection Agency, Development for Interim Final Effluent Limitations Guidelines and Proposed New Source Performance Standards for the Lead Segment of the Nonferrous Metals Manufacturing Point Source Category, EPA 440/1-75/032-9, Washington, D.C., February 1975.

IERL79 Industrial Environmental Research Laboratory, Control of Particulate Emissions in the Primary Nonferrous Metals Industries, NTIS Report No. PB-80-151822, Cincinnati, Ohio, December 1979.

APPENDIX A

ASSESSMENT METHODOLOGY

APPENDIX A: ASSESSMENT METHODOLOGY

CONTENTS

		Page
A.1	Introduction	A-5
A.2	Reference Facility	A-5
A.3	Generic Sites	A-5
A.4	Source Characterization	A-6
A.5	Environmental Pathway Modeling Computer Programs	A-6
A.6	Individual Assessment	A-10
A.7	Collective Assessment	A-11
A.8	AIRDOS-EPA Parameters and Input Data	A-12
A.9	DARTAB--Dose and Risk Tables	A-14
References		A-21

TABLES

A-1	Characteristics of the generic sites	A-7
A-2	Sources of food for the maximum individual	A-11
A-3	Some site parameters used with AIRDOS-EPA	A-13
A-4	Cattle densities and vegetable crop distributions for use with AIRDOS-EPA	A-15
A-5	Site independent parameters used for AIRDOS-EPA generic site assessments	A-17
A-6	Element dependent factors used in AIRDOS-EPA assessments	A-19

Preceding page blank

Appendix A: ASSESSMENT METHODOLOGY

A.1 Introduction

The general methodology used in the generic assessments presented in this report consisted of the following parts:

1) a description of a reference facility for the source category,

2) a choice of one or more generic sites appropriate to the source category,

3) an assignment of a source term (Ci/y) and source related quantities (e.g., release height, plume rise),

4) a calculation of individual and collective doses and risks due to air immersion, ground surface exposure, inhalation, and ingestion of radionuclides,

Assumptions made at each step were intended to be realistic without underestimating the impact of a release. The following sections describe these steps in more detail. (See Appendix B for health risk assessment details.)

A.2 Reference Facility

For each source category, a reference facility was designated. In some instances (e.g., nuclear power plants), extensive information was available on release rates and source considerations influencing dispersion (e.g., release height and exit velocity). In such cases, a reference facility was designed to represent an average facility for the source category. For other source categories (e.g., radiopharmaceutical industry), industry wide information was sparse. In these cases, data for a particular facility considered representative of the source category were used for the assessment.

A.3 Generic Sites

Generic sites were characterized for the purpose of assessing different source categories. These sites were chosen by

Preceding page blank

first identifying locations of facilities within each source category and then identifying a few of them which typified the types of locations where such facilities might be located. Factors which entered into this judgment included geographic location, population density, and food crop production.

On the basis of similarities between representative sites for the different source categories, seven generic sites (designated A, B, C, D, E, F, and G) were chosen which were believed to adequately represent potential sites for all of the source categories considered. For some source categories, one site was sufficient (e.g., uranium mining) while others required several sites to represent the source category (e.g. fossil fuel power plants). While the data used to characterize the generic sites were obtained for specific locations, there would not necessarily be a facility at that location for any specific source category.

Sites A and B represent urban and suburban locations, respectively. Site A characterizes a very large metropolitan city: the maximum case with respect to population density and overall population within 80 km (New York City, New York). Site B represents the near suburbs of a large Midwest city (St. Louis, Missouri). Site C was selected to depict the phosphate industry since this location has a heavy concentration of phosphate mining and milling (Polk County, Florida, near Bartow). Site D represents a rural setting in the central portion of the United States (near Little Rock, Arkansas). Site E exhibits the characteristics associated with the uranium industry and other mining endeavors (Grants, New Mexico). Site F is a remote, sparsely populated location in the Northwest which represents a minimal impact on the general population (near Billings, Montana). Site G (near Pocatello, Idaho) is representative of elemental phosphorous processing sites. Table A-1 gives the important characteristics of these generic sites.

A.4 Source Characterization

Sources were characterized by the release rate (Ci/year) of each emitted radionuclide. An effective release height was assigned to each source based on the release height and any expected plume rise. In general, no credit was given for plume rise unless it was clearly indicated.

A.5 Environmental Pathway Modeling Computer Programs

AIRDOS-EPA (Mo79) was used, as discussed in Volume I, Chapter 6, to calculate the individual and collective radionuclide concentrations for these assessments.

Table A-1. Characteristics of the generic sites

Site A--New York	
Meteorological data:	New York/LaGuardia (WBAN=14732)
Stability Categories:	A-F
Period of Record:	65/01-70/12
Annual Rainfall:	102 cm
Average Temperature:	12.1° C
Average Mixing Height:	1000 m
Population (0-8 km):	9.23E+5 persons
(0-80 km):	1.72E+7 persons
Dairy Cattle (0-80 km):	1.72E+5 head
Beef Cattle (0-80 km):	1.17E+5 head
Vegetable Crop Area: (0-80 km)	3.77E+4 ha

Site B--Missouri	
Meteorological data:	St. Louis/Lambert (WBAN=13994)
Stability Categories:	A-G
Period of Record:	60/01-64/12
Annual Rainfall:	102 cm
Average Temperature:	11.5° C
Average Mixing Height:	600 m
Population: (0-8 km):	1.34E+4 persons
(0-80 km):	2.49E+6 persons
Dairy Cattle (0-80 km):	3.80E+4 head
Beef Cattle (0-80 km):	6.90E+5 head
Vegetable Food Crop Area: (0-80 km)	1.64E+4 ha

Table A-1. Characteristics of the generic sites--continued

Site C--Florida

Meteorological data:	Orlando/Jet Port (WBAN=12815)
Stability Categories:	A-E
Period of Record:	74/01-74/12
Annual Rainfall:	142 cm
Average Temperature:	22.0° C
Average Mixing Height:	1000 m
Population: (0-10 km):	1.55E+3 persons
(0-80 km):	1.51E+6 persons
Dairy Cattle (0-80 km):	2.75E+4 head
Beef Cattle (0-80 km):	2.57E+5 head
Vegetable Crop Area: (0-80 km)	1.39E+4 ha

Site D--Arkansas

Meteorological data:	Little Rock/Adams (WBAN=13963)
Stability Categories:	A-F
Period of Record:	72/02-73/02
Annual Rainfall:	127 cm
Average Temperature:	14.8° C
Average Mixing Height:	600 m
Population: (0-8 km):	1.18E+4 persons
(0-80 km):	5.89E+5 persons
Dairy Cattle (0-80 km):	1.19E+4 head
Beef Cattle (0-80 km):	2.57E+5 head
Vegetable Crop Area: (0-80 km)	2.94E+3 ha

Table A-1. Characteristics of the generic sites--continued

Site E--New Mexico

Meteorological data:	Grants/Gnt-Milan (WBAN=93057)
Stability Categories:	A-F
Period of Record:	54/01-54/12
Annual Rainfall:	20 cm
Average Temperature:	13.2° C
Average Mixing Height:	800 m
Population: (0-8 km):	0 persons
(0-80 km):	3.60E+4 persons
Dairy Cattle (0-80 km):	2.30E+3 head
Beef Cattle (0-80 km):	8.31E+4 head
Vegetable Crop Area: (0-80 km)	2.78E+3 ha

Site F--Montana

Meteorological data:	Billings/Logan (WBAN=24033)
Stability Categories:	A-F
Period of Record:	67/01-71/12
Annual Rainfall:	20 cm
Average Temperature:	8.1° C
Average Mixing Height:	700 m
Population: (0-8 km):	0 persons
(0-80 km):	1.30E+4 persons
Dairy Cattle (0-80 km):	1.86E+3 head
Beef Cattle (0-80 km):	1.47E+5 head
Vegetable Crop Area: (0-80 km)	1.77E+4 ha

Table A-1. Characteristics of the generic sites--continued

Site G--Idaho	
Meteorological data:	Pocatello (WBAN=24156)
Stability Categories:	A-F
Period of Record:	54/01-62/12
Annual Rainfall:	27.4 cm
Average Temperature:	7.8° C
Average Mixing Height:	615 m
Population: (0-10 km):	4.17E+4 persons
(0-80 km):	1.40E+5 persons
Dairy Cattle (0-80 km):	1.72E+4 head
Beef Cattle (0-80 km):	1.45E+5 head
Vegetable Crop Area: (0-80 km)	1.44E+5 ha

Air concentrations are ground level sector averages. Dispersion is calculated from annual average meteorological data. Depletion due to dry deposition and precipitation scavenging is calculated for particulates and reactive vapors.

Ground surface and soil concentrations are calculated for those nuclides subject to deposition due to dry deposition and precipitation scavenging.

The output from AIRDOS-EPA contains calculated radionuclide intakes and external exposure. This file is used as input to DARTAB (Be81) to produce the dose and risk tables used in the individual and collective assessments. The dose and risk conversion factors used for these calculations are discussed in Volume I, Chapter 8.

A.6 Individual Assessment

The nearby individuals were assessed on the following basis:

1) The nearby individuals for each source category are intended to represent an average of individuals living near each facility within the source category. The location on the assessment grid which provides the greatest lifetime risk (all pathways considered) was chosen for the nearby individuals.

2) The organ dose-equivalent rates in the tables are based on the calculated environmental concentrations by AIRDOS-EPA. For inhaled or ingested radionuclides, the conversion factors are the 70-year values.

3) The individual is assumed to home-grow a portion of his or her diet consistent with the type of site. Individuals living in urban areas were assumed to consume much less home produced food than an individual living in a rural area. We assumed that in an agriculturally unproductive location, people would home-produce a portion of their food comparable to residents of an urban area, and so we used the urban fraction for such nonurban locations. The fractions of home produced food consumed by individuals for the generic sites are shown in Table A-2. Trial runs showed little difference between assuming that the balance of the nearby individuals' diet comes from the assessment area or from outside the assessment area.

Table A-2. Sources of food for the maximum individual

Food	Urban/Low productivity (Sites A, B, E-G)			Rural (Sites C & D)		
	F1	F2	F3	F1	F2	F3
Vegetables	.076	0.	.924	.700	0.	.300
Meat	.008	0.	.992	.442	0.	.558
Milk	0.	0.	1.	.399	0.	.601

F1 and F2 are the home-produced fractions at the individuals' location and within the 80 km assessment area, respectively. The balance of the diet, F3, is considered to be imported from outside the assessment area with negligible radionuclide concentrations due to the assessed source. Fractions are based on an analysis of household data from the USDA 1965-1966 National Food Consumption Survey (USDA72).

A.7 Collective Assessment

The collective assessment to the population within an 80 km radius of the facility under consideration was performed as follows:

1) The population distribution around the generic site was based on the 1970 census. The population was assumed to remain stationary in time.

2) Average agricultural production data for the state in which the generic site is located were assumed for all distances greater than 500 meters from the source. For distances less than 500 meters no agricultural production is calculated.

3) The population in the assessment area consumes food from the assessment area to the extent that the calculated production allows. Any additional food required is assumed to be imported without contamination by the assessment source. Any surplus is not considered in the assessment.

4) The collective organ dose-equivalent rates are based on the calculated environmental concentrations. Seventy-year dose commitment factors (as for the individual case) are used for ingestion and inhalation. The collective dose equivalent rates in the tables can be considered to be either the dose commitment rates after 100 years of plant operation, or equivalently, the doses which will become committed for up to 100 years from the time of release for one year of plant operation.

A.8 AIRDOS-EPA Parameters and Input Data

Site independent parameter values used for AIRDOS-EPA are summarized in Table A-5. Element dependent factors (Ba81) are listed in Table A-6.

Mixing Height and Deposition

Table A-3 summarizes the mixing heights, rainfall rates, and scavenging coefficients used for the generic sites. A dry deposition velocity of 0.0018 m/s was used for particulates and 0.035 m/s for reactive vapors (e.g., elemental iodine) unless otherwise indicated.

The average mixing height is the distance between the ground surface and a stable layer of air where no further mixing occurs. This average was computed by determining the harmonic mean of the morning mixing height and the afternoon mixing height for the location (Ho72). The rainfall rate (USGS70) determines the value used for the scavenging coefficient. Sites E through G are relatively dry locations as reflected by the scavenging coefficients.

Meteorological Data

STAR (an acronym for STability ARray) meteorological data summaries were obtained from the National Climatic Center, Asheville, North Carolina. Data for the station considered most representative for each generic site were used. Generally, these data are from a nearby airport. The station used is identified by the corresponding WBAN number in Table A-1. These data were converted to AIRDOS format wind data using the utility program listed in Appendix A of EPA80.

Table A-3. Some site parameters used with AIRDOS-EPA

Generic site	Average mixing height (m)	Rainfall rate (cm/y)	Scavenging coefficient (s^{-1})
Site A	1000	102	1.0E-5
Site B	600	102	1.0E-5
Site C	1000	142	1.4E-5
Site D	600	127	1.3E-5
Site E	800	20	2.0E-6
Site F	700	20	2.0E-6
Site G	615	27	2.7E-6

Dairy and Beef Cattle

Dairy and beef cattle distributions are part of the AIRDOS-EPA input. A constant cattle density is assumed except for the area closest to the source or stack in the case of a point source, i.e., no cattle within 500 m of the source. The cattle densities are provided by State in Table A-4. These densities were derived from data developed by NRC (NRC75). Milk production density in units of liters/day-square mile was converted to number of dairy cattle /square kilometer by assuming a milk production rate of 11.0 liters/day per dairy cow. Meat production density in units of kilograms/day-square mile was changed to an equivalent number of beef cattle/square kilometer by assuming a slaughter rate of .00381 day^{-1} and 200 kilograms of beef/animal slaughtered. A 180-day grazing period was assumed for dairy and beef cattle.

Vegetable Crop Area

A certain fraction of the land within 80 km of the source is used for vegetable crop production and is assumed to be uniformly distributed throughout the entire assessment area with the exception of the first 500 meters from the source. Information on the vegetable production density in terms of kilograms (fresh weight)/day-square mile were obtained from NRC data (NRC75). The vegetable crop fractions (Table A-4) by State were obtained from the production densities by assuming a production rate of 2 kilograms (fresh weight)/year-square meter (NRC77).

Population

The population data for each generic site were generated by a computer program, SECPOP (At74), which utilizes an edited and compressed version of the 1970 United States Census Bureau's "Master Enumeration District List with Coordinates" containing housing and population counts for each census enumeration district (CED) and the geographic coordinates of the population centroid for the district. In the Standard Metropolitan Statistical Areas (SMSA) the CED is usually a "block group" which consists of a physical city block. Outside the SMSAs the CED is an "enumeration district," which may cover several square miles or more in a rural area.

There are approximately 250,000 CEDs in the United States with an average population of about 800 persons. The position of the population centroid for each CED was marked on the district maps by the individual census official responsible for each district and is based only on personal judgment from inspection of the population distribution on the map. The CED entries are sorted in ascending order by longitude on the final data tape.

The resolution of a calculated population distribution cannot be better than the distribution of the CEDs. Hence, in a metropolitan area the resolution is often as small as one block, but in rural areas it may be on the order of a mile or more.

A.9 DARTAB--Dose and Risk Tables

The intermediate output files of ingestion and inhalation intake and ground level air and ground surface concentrations of radionuclides were processed by DARTAB (Be80) using dose and risk conversion factors (see Volume I, Chapters 7 and 8) to produce the dose and risk assessments for this report.

Table A-4. Cattle densities and vegetable crop distributions for use with AIRDOS-EPA

State	Dairy cattle density #/km^2	Beef cattle density #/km^2	Vegetable crop fraction km^2/km^2
Alabama	7.02E-1	1.52E+1	4.16E-3
Arizona	2.80E-1	3.73	2.90E-3
Arkansas	5.90E-1	1.27E+1	1.46E-3
California	2.85	8.81	1.18E-2
Colorado	3.50E-1	1.13E+1	1.39E-2
Connecticut	2.50E-1	3.60	7.93E-3
Delaware	2.72	6.48	5.85E-2
Florida	1.37	1.28E+1	6.92E-3
Georgia	8.63E-1	1.43E+1	2.17E-3
Idaho	8.56E-1	7.19	7.15E-2
Illinois	2.16	3.33E+1	2.80E-2
Indiana	2.80	3.34E+1	2.72E-2
Iowa	3.14	7.40E+1	2.43E-2
Kansas	8.00E-1	2.90E+1	5.97E-2
Kentucky	2.57	2.65E+1	3.98E-3
Louisiana	9.62E-1	1.08E+1	4.35E-2
Maine	8.07E-1	7.65E-1	5.97E-2
Maryland	6.11	1.09E+1	1.11E-2
Massachusetts	3.13	2.90	4.96E-3
Michigan	3.51	7.90	1.70E-2
Minnesota	4.88	1.85E+2	3.05E-2
Mississippi	8.70E-1	1.75E+1	1.07E-3
Missouri	1.89	3.43E+1	8.14E-3
Montana	9.27E-2	7.29	8.78E-3
Nebraska	8.78E-1	3.50E+1	2.39E-2
Nevada	5.65E-2	1.84	8.92E-3
New Hampshire	1.58	1.40	6.69E-2
New Jersey	3.29	4.25	1.82E-2
New Mexico	1.14E-1	4.13	1.38E-3
New York	8.56	5.83	1.88E-2

Table A-4. Cattle densities and vegetable crop distributions for use with AIRDOS-EPA--continued

State	Dairy cattle density $\#/km^2$	Beef cattle density $\#/km^2$	Vegetable crop fraction km^2/km^2
North Carolina	1.26	1.02E+1	6.32E-3
North Dakota	6.25E-1	1.18E+1	6.29E-2
Ohio	4.56	2.03E+1	1.70E-2
Oklahoma	7.13E-1	2.68E+1	2.80E-2
Oregon	4.53E-1	4.56	1.59E-2
Pennsylvania	6.46	9.63	1.32E-2
Rhode Island	2.30	2.50	4.54E-2
South Carolina	7.02E-1	8.87	1.84E-3
South Dakota	8.85E-1	2.32E+1	1.20E-2
Tennessee	2.00E-1	2.11E+1	2.72E-3
Texas	5.30E-1	1.90E+1	5.77E-3
Utah	4.46E-1	2.84	1.83E-3
Vermont	8.88	4.71	1.08E-3
Virginia	1.84	1.31E+1	8.70E-3
Washington	1.50	5.62	5.20E-2
West Virgina	6.00E-1	6.23	1.16E-3
Wisconsin	1.43E+1	1.81E+1	1.78E-2
Wyoming	5.79E-2	5.12	1.59E-3

Table A-5. Site independent parameters used for AIRDOS-EPA generic site assessments

Symbolic variable	Description	Value
BRTHRT	Breathing Rate (cm^3/h)	9.17E+5
T	Surface buildup time (days)	3.65E+4
DDI	Activity fraction after washing	0.5
TSUBH1	Time delay-pasture grass (h)	0.0
TSUBH2	Time delay-stored food (h)	2.16E+3
TSUBH3	Time delay-leafy vegetables (h)	336.
TSUBH4	Time delay-produce (h)	336.
LAMW	Weathering removal rate factor (h^{-1})	2.10E-3
TSUBE1	Exposure period-pasture (h)	720.
TSUBE2	Exposure period-crops or leafy vegetables (h)	1.44E+3
YSUBV1	Productivity-pasture (dry weight)(kg/m^2)	.280
YSUBV2	Productivity-crops and leafy vegetables (kg/m^2)	.716
FSUBP	Time fraction-pasture grazing	0.40
FSUBS	Pasture feed fraction-while pasture grazing	0.43
QSUBF	Feed or forage consumption rate (kg-dry/day)	15.6
TSUBF	Consumption delay time-milk (d)	2.0
UV	Vegetable utilization rate (kg/y)	176.
UM	Milk utilization rate (kg/y)	112.
UF	Meat utilization rate (kg/y)	85.
UL	Leafy vegetable utilization rate (kg/y)	18.
TSUBS	Consumption time delay-meat (days)	20.

Table A-5. Site independent parameters used for AIRDOS-EPA generic site assessments (Continued)

Symbolic variable	Description	Value
FSUBG	Produce fraction (garden of interest)	1.0
FSUBL	Leafy veg fraction (garden of interest)	1.0
TSUBB	Soil buildup time (y)	100.
P	Effective surface density of soil (kg/m^2)	215.
TAUBEF	Meat herd-slaughter rate factor (d^{-1})	3.81E-3
MSUBB	Mass of meat of slaughter (kg)	200.
VSUBM	Milk production rate of cow (L/d)	11.0
R1	Deposition interception fraction-pasture	0.57
R2	Deposition interception fraction-leafy vegetables	0.20

Table A-6. Element dependent factors used in AIRDOS-EPA assessments

Element	Clearance class	F_1	F_m (d/L)	F_f (d/kg)	Biv_1	Biv_2
Ac	Y	0.10E-2	2.0E-5	1.6E-6	1.0E-2	2.5E-3
Ac	W	0.10E-2	2.0E-5	1.6E-6	1.0E-2	2.5E-3
Ag	Y	0.50E-1	3.0E-2	1.7E-2	6.0E-1	1.5E-1
Am	Y	0.10E-2	3.6E-5	1.6E-6	9.8E-3	1.5E-3
As	W	0.30E-1	6.2E-5	2.0E-3	3.9E-3	1.7E-2
Ba	D	0.10	3.5E-4	3.2E-3	6.1E-2	2.0E-1
Be	W	0.20E-2	9.1E-7	1.0E-3	1.7E-3	4.2E-4
Bi	W	0.50E-1	5.0E-4	1.3E-2	6.0E-1	1.5E-1
Ce	Y	0.10E-3	2.0E-5	1.2E-3	2.6E-2	6.2E-3
Cm	Y	0.10E-2	2.0E-5	1.6E-6	1.3E-3	1.7E-3
Co	W	0.50E-1	2.0E-3	1.3E-2	3.7E-2	9.3E-3
Co	Y	0.50E-1	2.0E-3	1.3E-2	3.7E-2	9.3E-3
Cr	D	0.10	2.0E-3	2.4E-3	2.4E-2	6.0E-3
Cr	Y	0.10	2.0E-3	2.4E-3	2.4E-2	6.0E-3
Cs	D	0.95	5.6E-3	1.4E-2	1.4E-1	9.1E-3
Eu	Y	0.10E-3	2.0E-5	4.8E-3	1.0E-2	2.5E-3
Fe	W	0.10	5.9E-5	4.0E-2	9.3E-3	2.3E-3
Ga	W	0.10E-2	5.0E-5	1.4	1.0E-3	2.5E-4
Hg	W	0.20E-1	9.7E-6	2.6E-1	1.5	3.8E-1
Ir	Y	0.10E-1	2.0E-6	1.5E-3	5.2E+1	1.3E+1
I	D	0.95	9.9E-3	7.0E-3	2.0E-1	5.5E-2
La	W	0.10E-3	2.0E-5	2.0E-4	4.2E-3	1.1E-3
La	Y	0.10E-3	2.0E-5	2.0E-4	4.2E-3	1.1E-3
Mn	W	0.10	8.4E-5	8.0E-4	3.9E-2	9.8E-3
Mo	D	0.95	1.4E-3	8.0E-3	3.4	2.2E-1
Na	D	0.95	3.5E-2	3.0E-2	2.1E-1	5.2E-2
Nb	W	0.10E-1	2.0E-2	2.8E-1	3.8E-2	9.4E-3
Pa	Y	0.10E-2	5.0E-6	1.6E-6	1.0E-2	2.5E-3
Pb	W	0.80E-1	8.7E-5	9.1E-4	1.4E-1	4.8E-3
Po	W	0.10	1.2E-4	8.7E-3	4.2E-3	2.6E-4
Po	D	0.10	1.2E-4	8.7E-3	4.2E-3	2.6E-4
Pr	Y	0.10E-3	2.0E-5	4.7E-3	1.0E-2	2.5E-3
Pu	Y	0.30E-4	5.3E-8	1.9E-8	6.7E-3	1.1E-3
P	D	0.80	1.6E-2	4.6E-2	4.4E+0	1.1
Ra	W	0.20	5.9E-4	5.0E-4	1.0E-1	2.0E-2

Table A-6. Element dependent factors used in AIRDOS-EPA assessments (Continued)

Element	Clearance class	F_1	F_m (d/L)	F_f (d/kg)	Biv_1	Biv_2
Rb	D	0.95	1.2E-2	3.1E-2	2.5E-1	6.3E-2
Ru	W	0.40E-1	6.1E-7	1.8E-3	1.7E-1	1.6E-2
Ru	Y	0.40E-1	6.1E-7	1.8E-3	1.7E-1	1.6E-2
Sb	W	0.50E-1	2.0E-5	4.0E-3	1.1E-1	2.8E-2
Sn	W	0.50E-1	1.2E-3	8.0E-2	2.0E-2	5.0E-3
Sr	D	0.20	1.1E-3	3.0E-4	2.4	2.2E-1
S	D	0.95	1.6E-2	1.0E-1	2.4	5.9E-1
Tb	Y	0.10E-3	2.0E-5	4.4E-3	1.0E-2	2.6E-3
Tc	W	0.80	9.9E-3	8.7E-3	2.2E+2	1.1
Th	W	0.10E-2	5.0E-6	1.6E-6	6.3E-3	3.5E-4
Th	Y	0.10E-2	5.0E-6	1.6E-6	6.3E-3	3.5E-4
Tl	W	0.95	2.2E-2	4.0E-2	1.0	2.5E-1
U	Y	0.20E-2	1.4E-4	1.6E-6	2.1E-2	4.2E-3
U	D	0.50E-1	1.4E-4	1.6E-6	2.1E-2	4.2E-3
Y	W	0.10E-3	2.0E-5	4.6E-3	1.1E-2	4.3E-3
Zn	W	0.50	1.0E-2	3.0E-2	3.9E-1	9.8E-2
Zr	W	0.20E-2	8.0E-2	3.4E-2	6.8E-4	1.7E-4

REFERENCES

At74 Athey T. W., R. A. Tell, and D. E. Janes, 1974, The Use of an Automated Data Base in Population Exposure Calculations, from Population Exposures, Health Physics Society, CONF-74018, October 1974.

Ba81 Baes C. F. III and R. D. Sharp, A Directory of Parameters Used in a Series of Assessment Applications of the AIRDOS-EPA and DARTAB Computer Codes, ORNL-5710, Oak Ridge National Laboratory, Oak Ridge, Tennessee, March 1981.

Be81 Begovich C. L., K. F. Eckerman, E.C. Schlatter, S.Y. Ohr, and R. O. Chester, 1981, DARTAB: A program to combine airborne radionuclide environmental exposure data with dosimetric and health effects data to generate tabulation of predicted impacts. ORNL/5692, Oak Ridge National Laboratory, Tennessee, August 1981.

EPA80 Environmental Protection Agency, Radiological Impact Caused by Emissions of Radionuclides into Air in the United States, EPA 520/7-79-006, EPA, Office of Radiation Programs, Washington, D.C., December 1980.

Ho72 Holzworth G. C., 1972, Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States, Report AP-101, U. S. Office of Air Programs 1972.

Mo79 Moore R. E., C. F. Baes III, L. M. McDowell-Boyer, A. P. Watson, F. O. Hoffman, J. C. Pleasant, C. W. Miller, 1979, AIRDOS-EPA: A Computerized Methodology for Estimating Environmental Concentrations and Dose to Man from Airborne Releases of Radionuclides, EPA 520/1-79-009, EPA Office of Radiation Programs, Washington, D.C. 20460, December 1979.

USDA72 United States Department of Agriculture, 1972, Food Consumption of Households in the United States (Seasons and Year 1965-1966), Household Food Consumption Survey 1965-1966, Report No. 12, Agricultural Research Service, USDA, Washington, DC (March 1972).

USGS70 U.S. Geological Survey, 1970, The National Atlas, U. S. Department of the Interior, Washington, D.C.

APPENDIX B

RADIONUCLIDE EMISSIONS TO AIR FROM FORMER MANHATTAN ENGINEERING DISTRICT AND ATOMIC ENERGY COMMISSION SITES (FUSRAP)

APPENDIX B: RADIONUCLIDE EMISSIONS TO AIR FROM FORMER MANHATTAN ENGINEERING DISTRICT AND ATOMIC ENERGY COMMISSION SITES
(FUSRAP)

CONTENTS

Page

B.1 Background B-5

B.2 Current Status B-5

B.3 Potential for Airborne Releases B-13

B.4 Site Summaries B-13

B.5 Discussion B-16

TABLES

B-1 Formerly Utilized Sites Remedial Action Program (FUSRAP) Sites, March 1983 B-6

B-2 FUSRAP sites with legislative authority for remedial action B-11

B-3 FUSRAP sites without legislative authoirty for remedial action B-13

FIGURE

B-1 Radon concentration near the tailings pile B-18

Preceding page blank

Appendix B: RADIONUCLIDE EMISSIONS TO AIR FROM FORMER MANHATTAN ENGINEERING DISTRICT AND ATOMIC ENERGY COMMISSION SITES (FUSRAP)

B.1 Background

The original program for the development and use of atomic energy, established by the Army Corps of Engineers' Manhattan Engineering District (MED) and continued by the Atomic Energy Commission (AEC), was conducted under contract at Federally-, privately-, and institutionally-owned sites. When the contract terminated, the sites were decontaminated according to the health and safety criteria then in effect and were released for unrestricted use. Changing radiological criteria prompted the AEC to re-examine the radiological status of these sites in 1974, to determine if further remedial actions were required.

This re-examination was continued under the Energy Research and Development Administration (ERDA) and the Department of Energy (DOE) and was expanded to include radiological surveys of former MED/AEC sites. When the results of several site surveys showed that remedial actions would be necessary, the DOE initiated the Formerly Utilized Sites Remedial Action Program (FUSRAP) to identify all former MED/AEC sites and to resolve any site radiological problems. As of March 1983, 36 sites had been designated as FUSRAP sites. These sites, their locations, and present owners are listed in Table B-1.

B.2 Current Status

Of the 36 FUSRAP sites, determinations that remedial actions are required have been made for 22 sites and are pending for the remaining 14 sites. As shown in Table B-1, DOE has legal authority for carrying out remedial actions under the provisions of the Atomic Energy Act of 1954, as amended, at only 14 of the 36 FUSRAP sites. The status of remedial actions at these 14 sites is summarized in Table B-2. At 3 of the 14 sites, no determination has been made that remedial actions are required. At six sites, some actions have been initiated. Remedial actions have been completed at five sites.

At the 22 remaining sites (see Table B-3), the DOE's authority extends only to characterizing the radiological status of the site, determining the need for remedial action (completed for 11 sites), and

Preceding page blank

Table B-1. Formerly Utilized Sites Remedial Action Program (FUSRAP) Sites, March 1983

Site/Location	Ownership	Designated for remedial action	Authority for remedial action
* 1. Acid/Pueblo Canyon Los Alamos, NM	Los Alamos County, U.S. Government	Yes	Yes
2. Albany Metallurgical Research Center Albany, OR	U.S. Department of the Interior, Bureau of Mines	Pending	Yes
* 3. Ashland Oil Co. (No. 1) Tonawanda, NY	Ashland Oil Co.	Yes	No
4. Ashland Oil Co. (No. 2) Tonawanda, NY	Ashland Oil Co.	Pending	No
* 5. Bayo Canyon Los Alamos, NM	Los Alamos County	Yes	Yes
6. Chupadera Mesa, White Sands Missile Range, NM	Multiple Private Ownership	Pending	Yes
* 7. Clecon Metals, Inc. Cleveland, OH	Clecon Metals, Inc.	Yes	No
* 8. Conserv, Inc. Nichols, FL	Conserv, Inc.	Yes	No
* 9. E.I. DuPont DeNemours & Co. Deepwater, NJ	E.I. DuPont DeNemours & Co.	Yes	Yes

---

See footnote at end of table.

Table B-1. Formerly Utilized Sites Remedial Action Program (FUSRAP) Sites, March 1983 (Continued)

	Site/Location	Ownership	Designated for remedial action	Authority for remedial action
*10.	Gardiner, Inc. Tampa, FL	Gardiner, Inc.	Yes	No
11.	W. R. Grace & Co. Curtis Bay, MD	W. R. Grace & Co.	Pending	No
*12.	Guterl Steel Corp. Lockport, NY	Guterl Special Steel Co., Simmons Steel Division	Yes	No
13.	Harshaw Chemical Co. Cleveland, OH	Harshaw Chemical Co.	Pending	No
14.	Iowa State University Ames, IA	Iowa State University Municipality of Ames	Pending	No
*15.	Kellex/Pierpoint Research Facility Jersey City, NJ	Delco-Levco, Pierpoint Associates	Yes	Yes
*16.	Linde Air Products Tonawanda, NY	Union Carbide Corp., Linde Air Products Division	Yes	Yes
17.	Niagara Falls Storage Site (Vicinity Properties) Lewiston, NY	Town of Lewiston, Fort Conti Corp., S. Washuta, Niagara Mohawk Power Co., the Somerset Group, Inc., U.S. Air Force, Services Corporation of America	Yes	Yes

---

See footnote at end of table.

Table B-1. Formerly Utilized Sites Remedial Action Program (FUSRAP) Sites, March 1983 (Continued)

Site/Location	Ownership	Designated for remedial action	Authority for remedial action
*18. Mallinckrodt, Inc. St. Louis, MO	Mallinckrodt, Inc.	Yes	No
*19. Middlesex Landfill Middlesex, NJ	Borough of Middlesex, Middlesex Presbyterian Church	Yes	Yes
*20. Middlesex Sampling Plant, Middlesex and Piscataway, NJ	U.S. Government, Multiple Private Ownership	Yes	Yes
21. Monticello (Vicinity Properties) Monticello, UT	Multiple Private Ownership	Pending	No
*22. National Guard Armory, Chicago, IL	State of Illinois	Pending	No
23. Olin Chemical Corp. Joliet, IL	Olin Mathieson Chemical Corporation	Pending	No
*24. Palos Park Forest Preserve Cook County, IL	Cook County Forest Preserve District	Yes	No
25. Pasadena Chemical Co. Pasadena, TX	Pasadena Chemical Co.	Yes	No
*26. St. Louis Airport Storage Site St. Louis, MO	St. Louis Airport Authority	Yes	No

---

See footnote at end of table.

Table B-1. Formerly Utilized Sites Remedial Action Program (FUSRAP) Sites, March 1983 (Continued)

	Site/Location	Ownership	Designated for remedial action	Authority for remedial action
27.	St. Louis Airport Site (Vicinity Properties) St. Louis, MO	Multiple Private Ownership	Yes	Yes
*28.	Seaway Industrial Park Tonawanda, NY	Seaway Industrial Park Development Co., Inc.	Yes	No
*29.	Seneca Army Depot Romulus, NY	U.S. Army	Yes	No
*30.	Shpack Landfill Norton, MA	Ms. L. Shpack	Yes	Yes
31.	Staten Island Staten Island, NY	Unknown	Pending	No
*32.	Universal Cyclops, Inc. Aliquippa, PA	Vulcan Cyclops, Inc.	Pending	No
33.	University of California Berkeley, CA	University of California	Yes	Yes
*34.	University of Chicago Chicago, IL	University of Chicago	Pending	Yes

---

See footnote at end of table.

Table B-1. Formerly Utilized Sites Remedial Action Program
(FUSRAP) Sites, March 1983 (Continued)

Site/Location	Ownership	Designated for remedial action	Authority for remedial action
35. Ventron Corporation Beverly, MA	Thiokol Corporation	Pending	No
36. Watertown Arsenal Watertown, MA	Watertown Redevelopment Corporation	Pending	No

*Sites for which Radiological Survey Reports are publicly available; see References.

Table B-2. FUSRAP sites with legislative authority[(a)] for remedial action

Site name and location	Status of remedial action as of March 1983							
	Determine need and authority	Preliminary engineering completed	Select action options	Design engineering initiated	NEPA process completed	Select remedial action	Design engineering completed	Remedial action completed
Acid/Pueblo Canyon, Los Alamos, NM	X	X	X	X	X	X	X	X
Albany Metallurgical Research Center, Albany, OR	P							
Bayo Canyon, Los Alamos, NM	X	X	X	X	X	X	X	X
Chupadera Mesa, White Sands Missile Range, NM	P							
E.I. DuPont DeNemours & Co., Deepwater, NJ	X	P						
Kellex/Pierpoint Research Facility, Jersey City, NJ	X	X	X	X	X	X	X	X
Linde Air Products, Tonawanda, NY	X	X						
Niagara Falls Storage Site (Vicinity Properties) (Formerly the Lake Ontario Ordnance Works)								
(1) 19 acres of disposal facility	X	X	X	X	X	X	X	X
(2) central and west ditches	X	X	X	X	X	X	P	
(3) remaining 30 properties	P							

See footnotes at end of table.

Table B-2. FUSRAP sites with legislative authority(a) for remedial action (Continued)

Site name and location	Status of remedial action as of March 1983							
	Determine need and authority	Preliminary engineering completed	Select action options	Design engineering initiated	NEPA process completed	Select remedial action	Design engineering completed	Remedial action completed
Middlesex Municipal Landfill, Middlesex, NJ	X	P						
Middlesex Sampling Plant, Middlesex and Piscataway, NJ								
(1) 33 Off-site properties	X	X	X	X	X	X	X	X
(2) On-site	X	P	(remedial action suspended pending site of NJ action on selection of disposal site)					
St. Louis Airport Storage Site, (Vicinity Properties) St. Louis, MO	X	X	X					
Shpack Landfill, Norton, MA	X	X						
University of California, Berkeley, CA	X	X	X	X	X	X	X	X
University of Chicago, Chicago, IL	X							

(a)Authorized by the Atomic Energy Act of 1954 and amendments.

Status Legend: X - Phase completed; P - Partially completed

Table B-3. FUSRAP sites without legislative authority[a] for remedial action

Site name and location	Status of remedial action as of March 1983	
	Designated for remedial action	Preliminary engineering completed
Ashland Oil Co. (No. 2), Tonawanda, NY	P	
Ashland Oil Co. (No. 1), Tonawanda, NY	X	
Clecon Metals Inc., Cleveland, OH	X	
Conserv, Inc., Nichols, FL	X	
Gardiner, Inc., Tampa, FL	X	
Guterl Steel Corp., Lockport, NY	X	X
Harshaw Chemical Co., Cleveland, OH	P	
Iowa State University, Ames, IA	P	
Mallinckrodt, Inc., St. Louis, MO	X	P
Monticello (Vicinity Properties), UT	P	
National Guard Armory, Chicago, IL	P	
Olin Chemical Co., Joliet, IL	P	
Palos Park Forest Preserve, Cook County, IL	X	X
Pasadena Chemical Company, TX	X	
Seaway Industrial Park, Tonawanda, NY	X	P
Seneca Army Depot, Romulus, NY	X	X[b]
St. Louis Airport Storage Site, St. Louis, MO	X	P
Staten Island, NY	P	
Universal Cyclops Inc., Aliquippa, PA	P	
Ventron Corporation, Beverly, MA	P	
W. R. Grace and Co., Curtis Bay, MD	P	
Watertown Arsenal, Watertown, MA	P	

(a) Radiological surveys, determinations of need for remedial actions, and planning for these sites were conducted under the authority of the Atomic Energy Act of 1954, as amended. No legislative authority exists for conducting remedial actions at these sites.

(b) Department of Army is responsible for remedial action. No further action required under FUSRAP.

Status legend: X - Phase Completed, P- Partially Completed.

planning. Completion of remedial actions at these sites will require DOE to obtain additional legislative authority.

B.3 Potential for Airborne Releases

To assess the potential for airborne releases of radioactive materials from FUSRAP sites, we have reviewed all of the Radiological Survey Reports which are publicly available (see References). These reports cover 22 of the 36 sites. For the sites where no Radiological Survey Reports are available, we reviewed "A Background Report for the Formerly Utilized Manhattan Engineering District/Atomic Energy Commission Sites Program" (DOE/EV-0097), to determine the potential for significant airborne releases. Although the information contained in this document is mainly descriptive, it does not appear that any of these sites has a greater potential for airborne release than the sites for which Radiological Survey Reports are available*

Based on our review, eight representative sites were selected for further study including the St. Louis Storage site which appears to have the greatest emissions of radionuclides to air. The other seven sites were selected randomly, and indicate the range of potential releases from FUSRAP sites. All of these sites have been designated for remedial action.

B.4 Site Summaries

St. Louis Airport, St. Louis, MO

This 21.7 acre site adjacent to the St. Louis Airport was used to store residues of contaminated scrap from the Mallinckrodt Chemical Corporation's uranium-processing operation. Residues were stored in the open, in steel drums, and in an open concrete pit. All residues were removed from the site during 1966 and 1967.

The radiological survey of the site identified significant surface and subsurface contamination both on- and off-site. Measurements of external gamma radiation 1 meter above the surface ranged from near background levels (10 µR/hr) to 330 µR/hr. The highest measurement was off-site, and continuous exposure could result in an integrated dose equivalent of approximately 2.9 rem/year. Radon flux measurements averaged 6.3 pCi/m^2-sec, equivalent to an annual Rn-222 source term of approximately 17 Ci. On-site radon-222 measurements ranged from 30 to 130 fCi/L, and airborne concentrations of Ra-226, Th-230, Pb-210, U-238, and Ac-227 near the west fence (the point of highest concentrations), 14 fCi/m^3, 13 fCi/m^3, 30 fCi/m^3, 5 fCi/m^3, and 1.6 fCi/m^3, respectively.

---

*This judgment does not apply to the Niagara Falls Storage Site. We are waiting for DOE Monitoring Reports on this facility, and will update our findings as necessary when we have reviewed the data.

Ashland Oil Company, Tonawanda, NY

The 10-acre site was used to dispose of 8,000 tons of residue from ore processing operations at the Linde Air Products refinery. The residue, containing approximately 0.54 percent uranium, was spread over two-thirds of the site. In 1974, 6,000 cubic yards of residue were removed to the adjacent Seaway Industrial Park (see below), and the site developed for oil storage.

The radiological survey of the site identified extensive soil contamination. External gamma radiation 1 meter above the surface on the site ranges from 17 μR/hour (or slightly above the 8-14 μR/hour background level in the area) to 190 μR/hour, and averaged 33 μR/hour over the entire site. Continuous exposure to the highest and average measured gamma radiation would result in an integrated dose equivalent of approximately 1.6 rem/year and 0.3 rem/year, respectively. In addition, a radon flux of 7 pCi/m^2-sec was estimated as the average for the entire 10-acre site. This would result in an annual radon source term of approximately 9 Ci.

Bayo Canyon Area, Los Alamos, NM

Bayo Canyon was used from 1943 through 1961 as an experimental area for high explosives. Test assemblies of natural and depleted uranium using lanthanum-140 as a tracer were exploded in the area, dispersing approximately 1.3 curies of natural uranium, 1.2 curies of depleted uranium, and between 30 and 40 curies of strontium-90 (present as a contaminant of lanthanum-140). An additional 85 and 120 curies of strontium-90 were deposited in waste handling facilities in the area and some fraction migrated into the subsurface environment. The area was decontaminated in 1963, and most of the debris was removed. The area is currently used as a recreational area, although residential development has been proposed.

The radiological survey of the site shows no statistically significant difference between the airborne concentrations of Sr-90 or uranium in the Bayo Canyon area compared with other northern New Mexico locations.

Clecon Metals, Inc., Cleveland, OH

Two of the three buildings at this 3.5 acre industrial site were used in the production of granular thorium metal for MED/AEC. The contamination in these buildings was removed or covered due to construction modifications after the thorium operations were ended.

The radiological survey of the site indicates that most of the contamination is within the two buildings used for thorium processing. However, some surface contamination is present. External gamma exposure rates 1 meter from the surface average approximately 3 μR/hour higher than the normal 10 μR/hour in the area. Continuous exposure would result in an incremental dose above normal background of approximately 26 mrem/year. The average concentration of thorium-232 in the soil is 6 pCi/g. Assuming 6 pCi/g Th-232, resulting in 6 PCi/m^2-sec Rn-220, the annual source term for Rn-220 is estimated to be approximately 2.7 Ci.

E.I. du Pont de Nemours & Co., Deepwater, NJ

The 700-acre Chambers Works site is adjacent to Deepwater, NJ. MED/AEC operations involving uranium conversion were conducted at three buildings at the site and a low-level radioactive burial ground (licensed by New Jersey). Only one of the three buildings used for MED/AEC work is still standing.

The radiological survey of the site identified some surface contamination (primarily next to the remaining processing building), but the primary cause for remedial action is contamination of the building itself. The highest external gamma radiation level 1 meter above the surface was 23 μR/hour, with most measurements in the range of 3-6 μR/hour. Continuous exposure at the highest exposure rate would result in an integrated dose equivalent of approximately 0.2 rem/year. Radon daughter concentrations in air ranged from 0.0001 to 0.0006 WL.

Middlesex Sampling Plant, Middlesex and Piscataway, NJ

MED/AEC operations involving the sampling, weighing, assaying, and storing of uranium and thorium ores were conducted at six buildings on this 9.6 acre site.

The radiological survey of the Middlesex Sampling Plant identified extensive soil contamination and elevated external gamma exposure rates and radon and radon daughter concentrations. External gamma readings 1 meter above the surface ranged from 22 μR/hour to 147 μR/hour. The highest measurements were made both near the center of the site and along the site boundary. Continuous exposure at the maximum rate could result in an integrated dose of approximately 1.3 rem/year. The average radon emanation rate for the site was 3.2 pCi/m^2-sec, or approximately 4 Ci/year.

Off-site measurements were also made at the facility, and indicate widespread contamination beyond the site. External gamma levels as high as 235 μR/hour were measured off-site, and radon daughter concentrations ranged from 0.004 to 0.014 WL in off-site residences and commercial buildings.

Seaway Industrial Park, Tonawanda, NY

The site covers approximately 100 acres, of which 13 acres adjacent to the Ashland Oil Company were used to receive approximately 6,000 cubic yards of uranium-processing residue.

The radiological survey identified significant surface contamination in the three areas where residues from the Ashland Oil property were dumped. External gamma levels as high as 80 μR/hour were measured; continuous exposure could result in an integrated dose equivalent of approximately 0.7 rem/year. The radon emanation rate from the site is estimated at 5 pCi/m^2-sec, equivalent to an annual release of about 8 Ci of Rn-222.

Seneca Army Depot, Romulus, NY

Eleven munitions bunkers at the facility were used to store pitchblende ore. When MED/AEC activities terminated, the bunkers reverted to use as munitions bunkers.

A radiological survey of the site indicates that significant contamination of the bunkers occurred. However, this contamination is limited to the bunkers themselves and the soil immediately surrounding the entrances. Most of the measurements of soil were at background levels, and it does not appear that this facility has any significant potential for airborne contamination or direct gamma irradiation outside the bunkers.

B.5 Discussion

It is reasonable to assume that the most significant airborne emission from a typical FUSRAP site during normal conditions (not during decommissioning operations) is that of radon. To estimate radon concentrations from the reported emission rates and site areas, we used Figure B-1. This figure presents radon concentrations in pCi/liter as a function of distance from the center of a tailings pile, for various pile sizes and a fixed radon emission rate of 280 pCi/m^2-sec. The figure suggests that the radon concentration at the fencepost is rather insensitive to pile size.

For the above eight sites, on-site radon concentrations in the range of 0.1 to 0.2 pCi/liter are estimated, with fencepost concentrations in the range of 0.025 to 0.05 pCi/liter. These radon concentrations translate into radon daughter levels of 0.001 to 0.002 WL on-site, and 2.5×10^{-4} to 5.0×10^{-4} WL at the fencepost. The levels at the fencepost are in the range of 0.008 to 0.017 of the 10 CFR 20 MPC (3 pCi/liter). The estimated lifetime risk of fatal cancer at the fencepost to the nearby individuals is in the range of 3×10^{-4} to 6×10^{-4}.

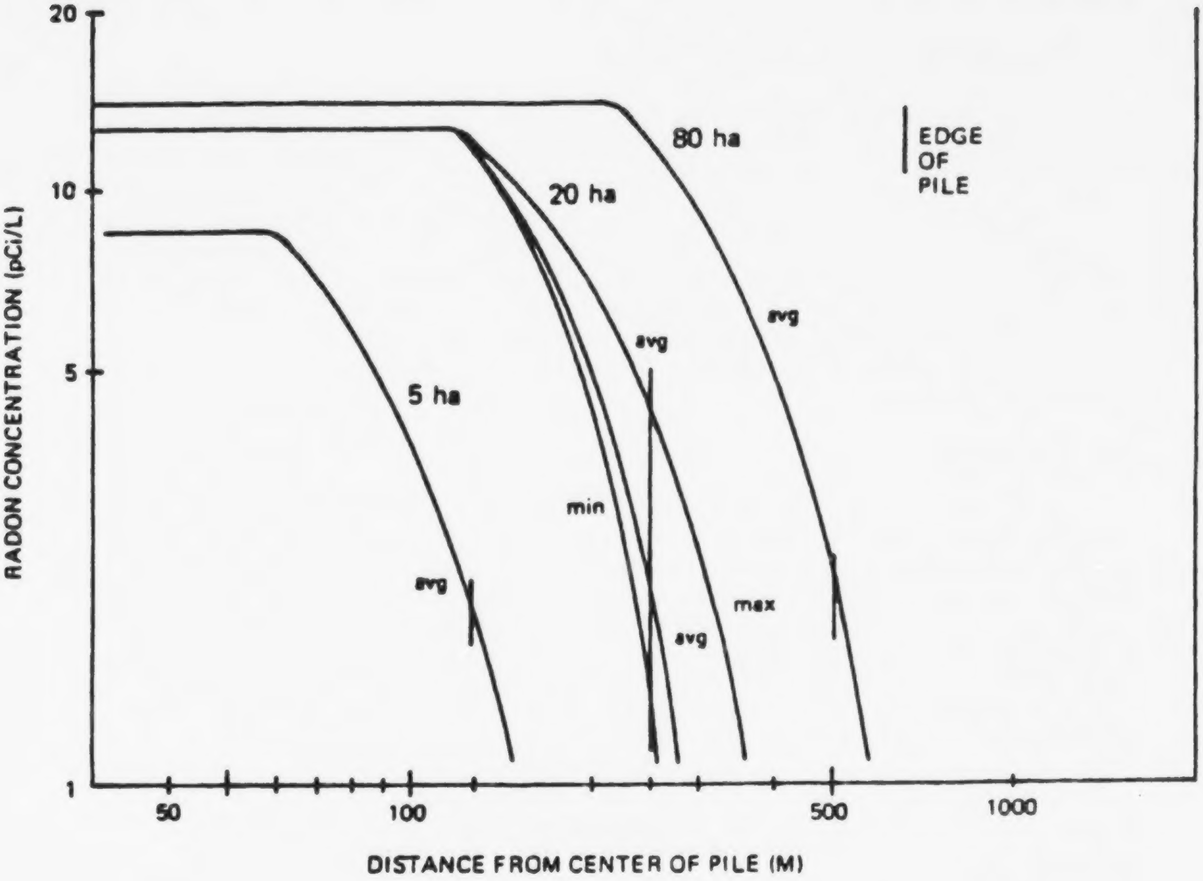


Figure B-1. Radon concentration near the tailings pile. Radon emission rate is 280 pCi/m^2s.

Source: "Draft Environmental Impact Statement for Standards for the Control of Byproduct Materials from Uranium Ore Processing." U.S. Environmental Protection Agency. EPA 520/1-82-022, p. 5-9, March 1983.

REFERENCES

1. "A Background Report for the Formerly Utilized Manhattan Engineering District/Atomic Energy Commission Sites Program," U.S. Department of Energy, September 1980.

2. "A Report to Congress to Accompany the Proposed Residual Radioactive Material Control Act." Draft Report, U.S. Department of Energy, ORNL/Sub-80/13829/1, June 1980.

3. "Formerly Utilized MED/AEC Sites Remedial-Action Program, Radiological Survey of Kent Chemical Laboratory, The University of Chicago, Chicago, Illinois, September 7-13, 1977, Final Report," U.S. Department of Energy, DOE/EV-0005/25, May 1982.

4. "Formerly Utilized MED/AEC Sites Remedial-Action Program, Radiological Survey of Ryerson Physical Laboratory, The University of Chicago, Chicago, Illinois, September 11-25, 1976, Final Report," U.S. Department of Energy, DOE/EV-0005/23, May 1982.

5. "Formerly Utilized MED/AEC Sites Remedial-Action Program, Radiological Survey of Site A, Palos Park Forest Preserve, Chicago, Illinois, Final Report," U.S. Department of Energy, DOE/EV-0005/7, April 1978.

6. "Formerly Utilized MED/AEC Sites Remedial-Action Program, Radiological Survey of the Ashland Oil Company, (Former Haist Property), Tonawanda, New York, Final Report," U.S. Department of Energy, DOE/EV-0005/4, May 1978.

7. "Formerly Utilized MED/AEC Sites Remedial-Action Program, Radiological Survey of the Bayo Canyon, Los Alamos, New Mexico, Final Report," U.S. Department of Energy, DOE/EV-0005/15, June 1979.

8. "Formerly Utilized MED/AEC Sites Remedial-Action Program, Radiological Survey of the Building Site 421, United States Watertown Arsenal, Watertown, MA, Final Report," U.S. Department of Energy, DOE/EV-0005/19, February 1980.

9. "Formerly Utilized MED/AEC Sites Remedial-Action Program, Radiological Survey of the E.I. DuPont DeNemours and Co., Deepwater, New Jersey, Final Report," U.S. Department of Energy, DOE/EV-0005/8, December 1978.

10. "Formerly Utilized MED/AEC Sites Remedial-Action Program, Radiological Survey of the Former GSA 39th Street Warehouse, 1716 Pershing Road, Chicago, Illinois, Final Report," U.S. Department of Energy, DOE/EV-0005/9, January 1978.

REFERENCES
(Continued)

11. "Formerly Utilized MED/AEC Sites Remedial-Action Program, Radiological Survey of the Former Horizons Inc., Metal Handling Facility, Cleveland, Ohio, Final Report," U.S. Department of Energy, DOE/EV-0005/10, February 1978.

12. "Formerly Utilized MED/AEC Sites Remedial-Action Program, Radiological Survey of the Former Linde Uranium Refinery, Tonawanda, New York, Final Report," U.S. Department of Energy, DOE/EV-0005/5, May 1978.

13. "Formerly Utilized MED/AEC Sites Remedial-Action Program, Radiological Survey of the Former Simonds Saw and Steel Co., Lockport, New York, Final Report," U.S. Department of Energy, DOE/EV-0005/17, November 1979.

14. "Formerly Utilized MED/AEC Sites Remedial-Action Program, Radiological Survey of the Former Virginia-Carolina Chemical Corporation Uranium Recovery Pilot Plant, Nichols, Florida, Final Report," U.S. Department of Energy, DOE/EV-0005/18, January 1980.

15. "Formerly Utilized MED/AEC Sites Remedial-Action Program, Radiological Survey of the George Herbert Jones Chemical Laboratory, The University of Chicago, Chicago, Illinois, June 13-17, 1977, Final Report," U.S. Department of Energy, DOE/EV-0005/26, May 1982.

16. "Formerly Utilized MED/AEC Sites Remedial-Action Program, Radiological Survey of the Middlesex Municipal Landfill, Middlesex, New Jersey, Final Report," U.S. Department of Energy, DOE/EV-0005/20, April 1980.

17. "Formerly Utilized MED/AEC Sites Remedial-Action Program, Radiological Survey of the Middlesex Sampling Plant, Middlesex, New Jersey, Final Report," U.S. Department of Energy, DOE/EV-0005/1, November 1977.

18. "Formerly Utilized MED/AEC Sites Remedial-Action Program, Radiological Survey of the Museum of Science and Industry, 57th Street and Lake Shore Drive, Chicago, Illinois, Final Report," U.S. Department of Energy, DOE/EV-0005/13, February 1979.

19. "Formerly Utilized MED/AEC Sites Remedial-Action Program, Radiological Survey of the Seaway Industrial Park, Tonawanda, New York, Final Report," U.S. Department of Energy, DOE/EV-0005/6, May 1978.

REFERENCES
(Continued)

20. "Formerly Utilized MED/AEC Sites Remedial-Action Program, Radiological Survey of the Seneca Army Depot, Romulus, New York, Final Report," U.S. Department of Energy, DOE/EV-0005/11, February 1979.

21. "Formerly Utilized MED/AEC Sites Remedial-Action Program, Radiological Survey of the Site of a Former Radioactive Liquid Waste Treatment Plant (TA-45) and the Effluent Receiving Areas of Acid, Pueblo, and Los Alamos Canyons, Los Alamos, New Mexico, Final Report," U.S. Department of Energy, DOE/EV-0005/30, May 1981.

22. "Formerly Utilized MED/AEC Sites Remedial-Action Program, Radiological Survey of the St. Louis Airport Storage Site, St. Louis, Missouri, Final Report," U.S. Department of Energy, DOE/EV-0005/16, September 1979.

23. "Formerly Utilized MED/AEC Sites Remedial-Action Program, Radiological Survey of the Universal Cyclops Inc. Titusville Plant, (Formerly Vulcan Crucible Steel Company) Aliquippa, Pennsylvania, May 2-8, 1978, Final Report," U.S. Department of Energy, DOE/EV-0005/33, May 1982.

24. "Formerly Utilized MED/AEC Sites Remedial-Action Program, Radiological Survey of the West Stands, New Chemistry Lab and Annex, and Ricketts Laboratory, The University of Chicago, Chicago, Illinois, August 31-September 2, 1977, Final Report," U.S. Department of Energy, DOE/EV-0005/34, May 1982.

25. "Radiological Survey of Properties in the Middlesex, New Jersey, Area, Supplement, Final Report," U.S. Department of Energy, DOE/EV-0005/1, March 1981.

26. "Radiological Survey of the Former Kellex Research Facility, Jersey City, New Jersey, Final Report," U.S. Department of Energy, DOE/EV-0005/29, February 1982.

27. "Radiological Survey of the Former Uranium Recovery Pilot and Process Sites, Gardiner, Incorporated, Tampa, Florida, Final Report," U.S. Department of Energy, DOE/EV-0005/21, March 1981.

28. "Radiological Survey of the Mallinckrodt Chemical Works, St. Louis, Missouri, Final Report," U.S. Department of Energy, DOE/EV-0005/27, December 1981.

29. "Radiological Survey of the Shpack Landfill, Norton, Massachusetts, Final Report," U.S. Department of Energy, DOE/EV-0005/31, December 1981.

REFERENCES
(Continued)

30. "Draft Environmental Impact Statement for Standards for the Control of Byproduct Materials from Uranium Ore Processing (40 CFR 192)," U.S. Environmental Protection Agency, EPA 520/1-82-022, March 1983.

APPENDIX C

RADON EMISSIONS FROM DEPARTMENT OF ENERGY AND NUCLEAR REGULATORY COMMISSION LICENSED FACILITIES

APPENDIX C: RADON EMISSIONS FROM DEPARTMENT OF ENERGY AND NUCLEAR REGULATORY COMMISSION LICENSED FACILITIES

CONTENTS

		Page
C.1	DOE Facilities	C-5
	DOE References	C-20
C.2	Nuclear Regulatory Commission Source Material Licensees	C-21
	NRC References	C-29

TABLES

C-1	^{222}Radon concentrations (pCi/l) at the Niagara Falls storage site	C-11
C-2	Surface area, volume, and content of the Weldon Spring Raffinate Pits	C-13
C-3	Radioactive wastes stored in Weldon Spring Quarry	C-15
C-4	Radon concentrations at the Weldon Spring site, 1982	C-56

FIGURES

C-1	Feed Materials Production Center Environmental Features	C-7
C-2	Radioactive waste storage locations and fencepost radon monitors	C-9
C-3	Weldon Spring Raffinate Pits area	C-12
C-4	Weldon Spring Quarry site	C-17
C-5	The Middlesex Sampling Plant site	C-18
C-6	Fansteel Metals Plant site	C-22
C-7	Molycorp Plant site	C-24
C-8	Stepan Chemical plant site	C-25
C-9	Diagram of the Kerr-McGee facility	C-27

Preceding page blank

Appendix C: RADON EMISSIONS FROM DEPARTMENT OF ENERGY- AND NUCLEAR REGULATORY COMMISSION-LICENSED FACILITIES

This report presents information on radon emissions from Department of Energy (DOE) and Nuclear Regulatory Commission (NRC) licensed facilities.

C.1 DOE Facilities

To determine which DOE sites have radon emissions, we reviewed environmental monitoring, radiological survey, hazard characterization, engineering evaluation, and environmental assessment reports prepared for DOE facilities. Our review of these sources identified four sites where uranium residues and wastes are stored or where previous operations involving uranium and thorium resulted in significant contamination of soils.* Releases of ^{222}radon from these sites are found to be large enough to cause radon concentrations at the site boundaries that are detectable in the presence of the naturally occurring radon.**

Identified as having potentially significant radon releases are the following five sites: (1) Feed Materials Production Center (FMPC), Fernald, OH; (2) Niagara Falls Storage Site (NFSS), Lewiston, NY; (3) Weldon Spring Site (WSS), Weldon Spring, MO; (4) Middlesex Sampling Plant (MSP), Middlesex, NJ; and (5) Monticello Uranium Mill Tailings Pile (MUMT), Monticello, Utah. Brief descriptions of each of these sites, the source of the radon emissions, and the approximate amounts of radon emissions are presented below.

The Feed Materials Production Center

The FMPC, near Fernald, OH, is a prime contractor site operated by National Lead of Ohio (NLO) for the DOE. The FMPC produces purified

---

* Once our literature review was completed, we verified the comprehensiveness of our findings during conversations with cognizant DOE personnel. We believe that the sites covered in this report are the only DOE facilities where radon emissions are large enough to be of concern.

** The source term at the Weldon Spring Site also includes ^{220}radon from the thorium wastes at the sites.

Preceding page blank

uranium metal and components for use at other DOE facilities. Feed materials include ore concentrates, recycled uranium from spent reactor fuel, and various uranium compounds. Thorium can also be processed at the site. Only minor amounts of radon are released from the production operations conducted at the site. The primary source of radon emissions at the FMPC is pitchblende residues stored in two concrete storage tanks. As shown in Figure C-1, the storage tanks are located on the western portion of the site, south of the chemical waste pits and approximately 325 meters from the western site boundary.

The pitchblende residues were received from the Mallinckrodt Uranium Refinery in St. Louis, MO, during the period that the Mallinckrodt plant was operated for the Atomic Energy Commission (AEC). Until June 1983, the residues were owned by AFRIMET (the U.S. subsidiary of the Belgian firm that originally supplied the ores) and stored under a lease storage agreement with the DOE. Upon expiration of the agreement, AFRIMET paid a reported fee of eight million dollars and transferred ownership of the residues (and additional residues stored at the NFSS, see below) to the United States (St83).

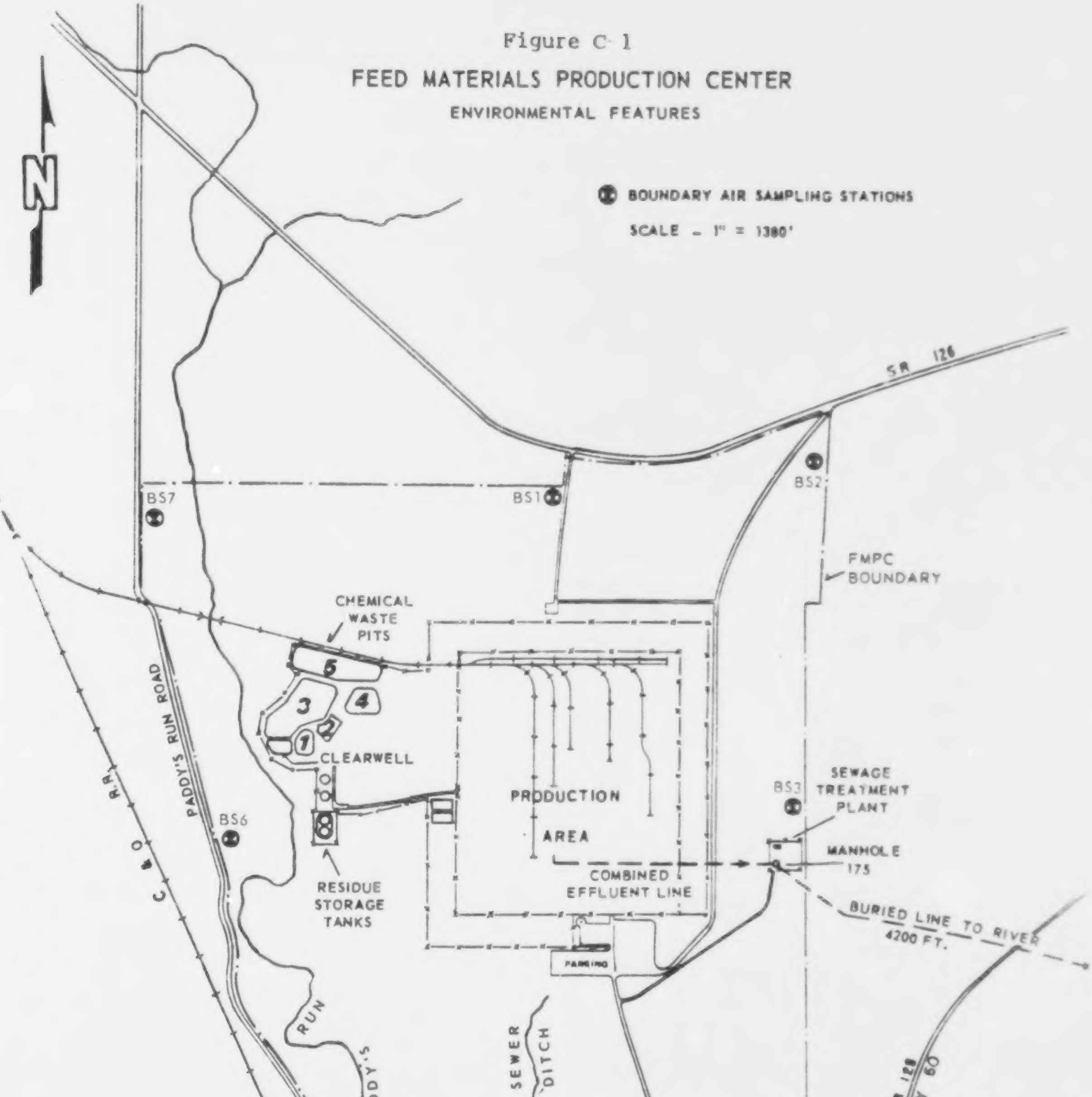
The residues are reported to have a radium concentration of 0.2 ppm, equivalent to about 200,000 pCi/g ^{226}Ra. The 8,790 metric tonnes of residue contain almost 1,760 curies of radium. Residues are stored in two concrete tanks. Earthen berms have recently been erected around the tanks to reduce gamma exposure. FMPC is awaiting the result of an engineering analysis before placing earthen covers on top of the concrete covers of the tanks (St83). The placement of earthern covers on the tanks could result in lower radon emissions as well as reduced gamma exposures.

No measurements of current emission rates of radon-222 on these tanks are available. However, data from the 1981 monitoring report (NL082), show average radon concentrations at the site boundaries ranging from 0.28 to 0.70 pCi/l. These data are presented below. The locations of the monitors are shown in Figure C-1.

^{222}Radon Concentrations in Air
at the FMPC Boundary, 1981

Location of Monitor	Number of Samples	Range Maximum pCi/l	Range Minimum pCi/l	Average pCi/l
BS1	4	0.94	0.11	0.58
BS2	4	1.35	0.17	0.61
BS3	3	0.60	0.13	0.42
BS4	4	0.66	0.05	0.34
BS5	3	0.40	0.08	0.28
BS6	4	0.80	0.34	0.57
BS7	3	1.07	0.30	0.70

Figure C-1
FEED MATERIALS PRODUCTION CENTER
ENVIRONMENTAL FEATURES


N
● BOUNDARY AIR SAMPLING STATIONS
SCALE - 1" = 1380'
SR 126
BS1
BS2
BS3
BS4
BS5
BS6
BS7
FMPC BOUNDARY
CHEMICAL WASTE PITS
5
4
3
2
1
CLEARWELL
RESIDUE STORAGE TANKS
PRODUCTION AREA
COMBINED EFFLUENT LINE
SEWAGE TREATMENT PLANT
MANHOLE 175
BURIED LINE TO RIVER 4200 FT.
PARKING
C & O R.R.
PADDY'S RUN ROAD
PADDY'S RUN
STORM SEWER OUTFALL DITCH
WILLEY ROAD
SR 128 US BY 60
RIVER ROAD

Data from an off-site monitor located approximately 13 kilometers east-northeast of the site showed an average ^{222}Rn concentration of 0.67 pCi/l, while a single measurement at a location eight kilometers west-northwest indicated 0.36 pCi/l.

The Niagara Falls Storage Site

The NFSS in Lewiston, NY, is a DOE surplus facility, operated by Bechtel National, Inc. The 77-hectare site is part of the former Lake Ontario Ordnance Works, and is used solely for the storage of uranium and pitchblende residues. The residues are stored in six buildings that were originally part of the facility's water treatment plant and in a spoils pile north of Building 411 (see Figure C-2). The major residues stored at the NFSS are summarized below:

Major Pitchblende Residues Stored
at the DOE-Niagara Falls Storage Site

Residue I.D.	Storage Location	Weight Metric Tonnes	Volume m^3	Surface Area, m^2	^{226}Radium Content
K-65	Bldg. 434	3,530	3,080	117	~200 ppb
L-30	Bldg. 411	7,460	6,020	1,860(a)	~10 ppb
L-50	Bldgs. 413-414	1,700	1,624	562	~10 ppb
F-32	Recarb. Pit	130	110-336	unknown	unknown
Middlesex Sands	Bldg. 410	2	175	unknown	unknown
R-10	Spoil Pile, N of Bldg. 411	7,470(b)	7,084(b)	37,373	~3 ppb

Source: Ba81

(a) these residues are partially covered by water.

(b) approximate weight and volume at time of emplacement; contaminated material includes ~11,340 m^3 of overburden and ~35,000 m^3 of contaminated soil. Unknown quantities of wastes have been added to the pile during remedial actions at the NFSS.

As noted, the residue storage buildings at the NFSS were originally part of the facility's water treatment plant. The K-65 residues are stored in Building 434 (see Figure C-2), which is the old water header tank for the system. The tank is a concrete silo, 50 meters tall. The top loading port of the silo was capped and sealed during the fall of

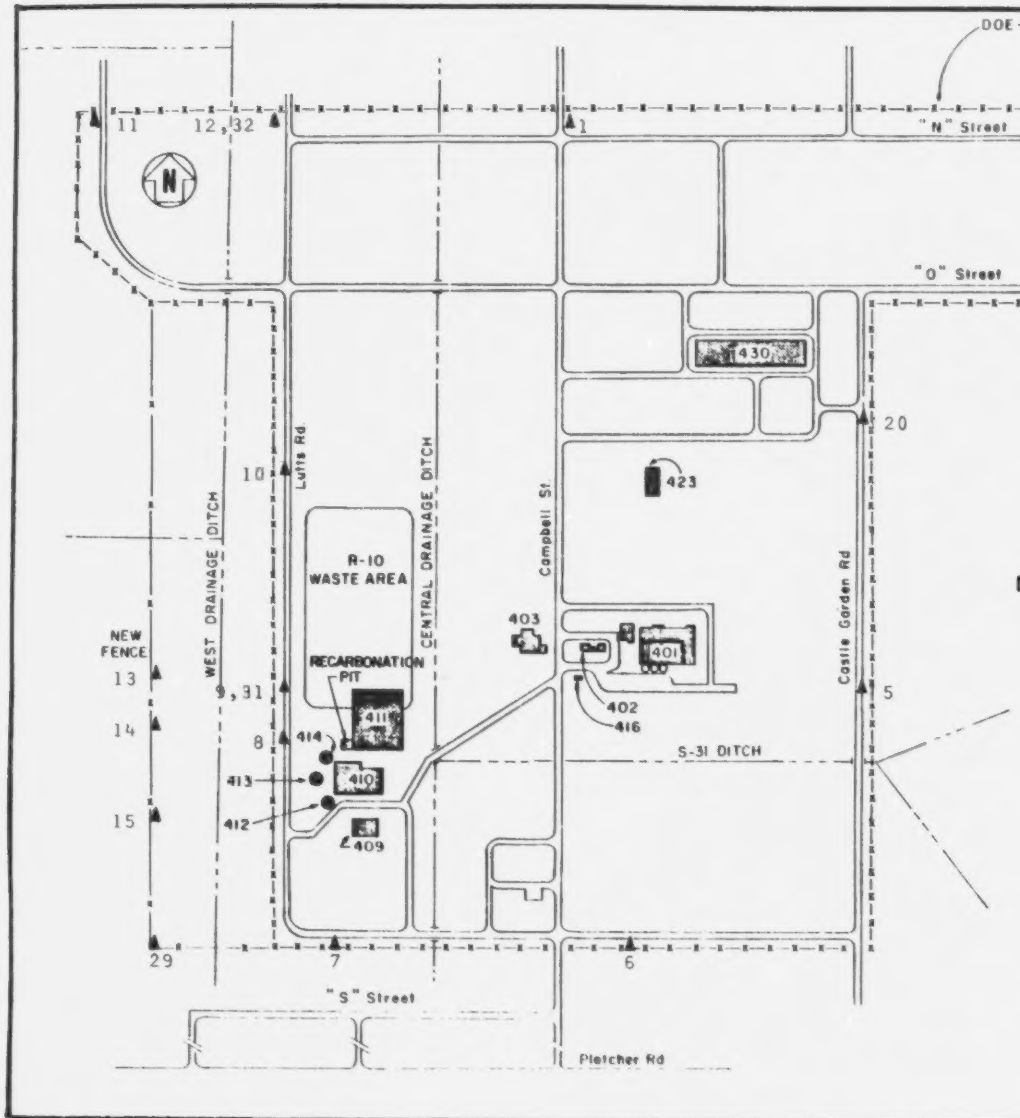

DOE-NFSS FENCELINE
34
"N" Street
11
12,32
1
434
3
"O" Street
4
430
20
423
10
Lutts Rd
R-10
WASTE AREA
CENTRAL DRAINAGE DITCH
WEST DRAINAGE DITCH
Campbell St
403
401
402
416
Castle Garden Rd
5
NEW
FENCE
13
9,31
RECARBONATION
PIT
411
14
8
414
413
410
412
409
15
S-31 DITCH
29
7
6
"S" Street
Pletcher Rd

Figure C-2
RADIOACTIVE WASTE
STORAGE LOCATIONS AND
FENCEPOST RADON MONITORS

DOE-NIAGARA FALLS STORAGE SITE

LOCATION		MATERIAL
BLDG. 410	-	MIDDLESEX SAND STORAGE
" 411	-	(RECARB PIT) F-32 RESIDUE
" 411	-	L-30 RESIDUE
" 413	-	L-50 "
" 414	-	L-50 "
" 434	-	K-65 "

SCALE: 1" = 525'

1980. The other residue storage buildings are isolated from the 434 silo, on the southwest section of the site. Buildings 413-414 are also water storage tanks, approximately 19 meters in diameter. Buildings 410, 411, and the recarbonation pit are located adjacent to the 413-414 storage tanks. The R-10 spoils pile is north of Building 411. The spoils pile originally contained the R-10 wastes, but contaminated soil and materials from on-site and off-site cleanup activities have also been placed on the pile.

Radon monitoring at the NFSS during 1980 and 1981 showed radon concentration at the site boundary west of the R-10 spoils pile in excess of the DOE standard of 3.0 pCi/l. To reduce exposures, a new fenceline was established 145 meters west of the former western exclusion boundary and remedial actions were initiated to reduce radon emissions from the site. Much of the cleanup, which is scheduled for completion during 1985, centers on cutting and diking the R-10 spoils pile. Additional effort is being placed on sealing buildings and cleaning up contaminated portions of the site (Ba84). The effectiveness of these activities can be partially seen by comparing the 1981 and 1982 radon concentrations at the site boundary. Annual average concentrations reported in the 1981 and 1982 Environmental Monitoring Reports (Be82 and Be83a) are presented in Table C-1. Figure C-2 shows the monitoring locations corresponding to the monitor ID's given in the table. Radon monitoring results for 1983 should be available by May of 1984. The 1983 data should confirm or deny the effectiveness of the remedial actions that have been taken at the NFSS.

The Weldon Spring Site

The WSS, near Weldon Spring, MO, is a DOE surplus facility operated by Bechtel National, Inc. Like the NFSS, it is used for the storage of uranium and thorium wastes. The site consists of two separate properties: the 21-hectare Raffinate Pits site; and the 3.6-hectare Quarry site, located about six kilometers southwest of the Raffinate Pits area.

The Raffinate Pits area (see Figure C-3) is a remnant of the Weldon Spring Chemical Plant. During the period that the chemical plant was operated for the Atomic Energy Commission, the four raffinate pits received residues and waste streams from the uranium and thorium processes conducted at the facility. Pits one and two contain neutralized raffinates from uranium refining operations and washed slag residues from uranium metal production operations. Pits 3 and 4 contain uranium wastes similar to those contained in Pits 1 and 2. In addition, they contain thorium contaminated raffinate solids from processing thorium recycle materials. During decontamination of the Chemical Plant, drummed wastes and contaminated rubble were disposed of in Pit 4. The surface areas, volumes, and contents of the pits are summarized in Table C-2. Surface water (varying in depth with the seasons) always

Table C-1. ^{222}Radon concentrations (pCi/l) at the Niagara Falls storage site

Monitor I.D.	Average 1981(a)	Average 1982(b,c)
01	0.91	1.15
02	0.32	NR
03	0.30	0.60
04	0.31	0.71
05	0.30	0.62
06	0.48	0.65
07	1.33	1.02
08	4.06	2.32
09	4.82	2.97
10	4.75	1.93
11	1.40	0.89
12	1.10	0.83
13	NR	0.88
14	NR	0.68
15	NR	0.76

Sources: Be82 and Be83a

(a) Measurements made by Mound Laboratory.

(b) Measurements made by Bechtel National, Inc.

(c) According to Be82, the monitors used by Bechtel average approximately 25 percent higher than the monitors used by Mound.

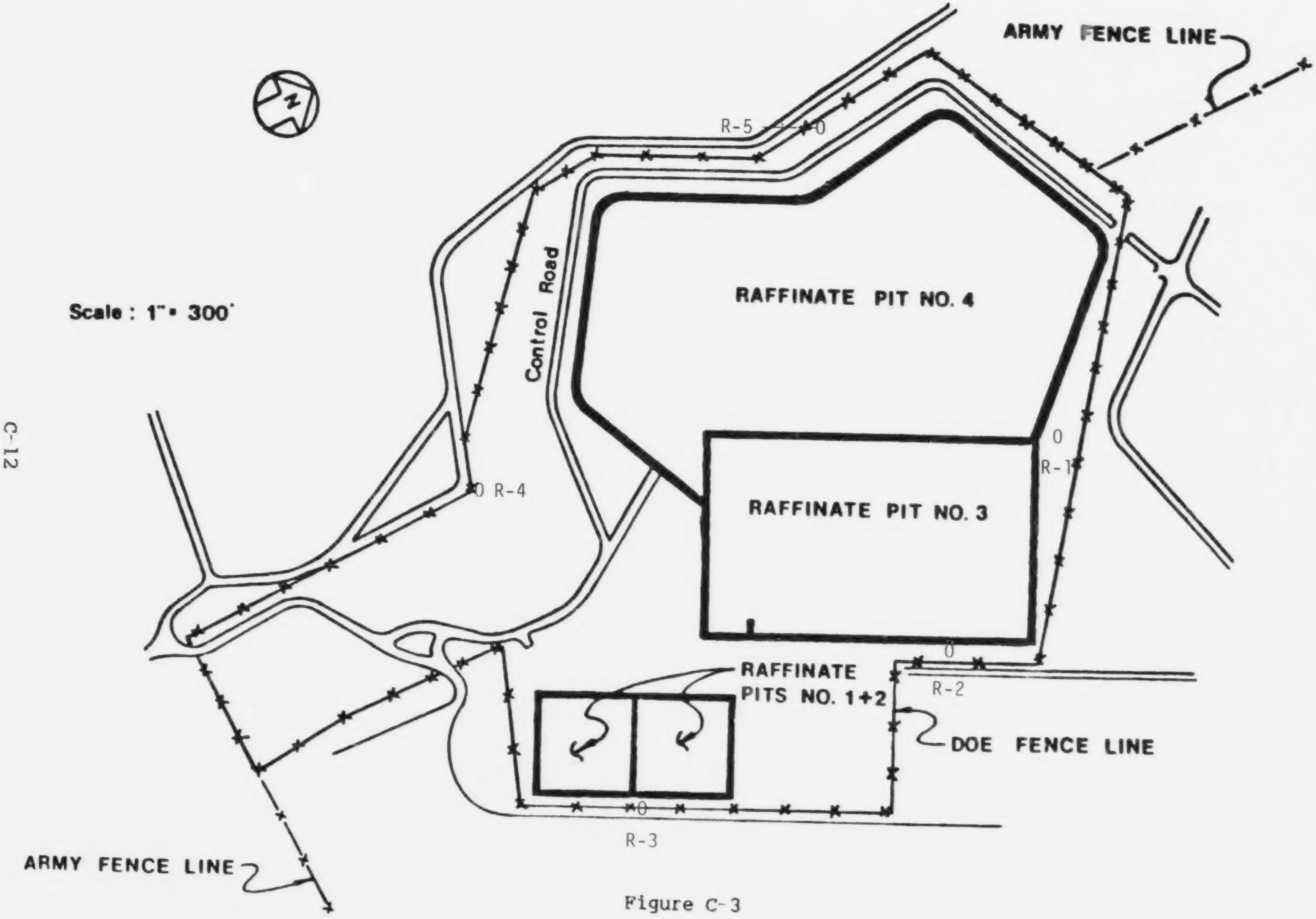

Scale : 1" = 300'
N
ARMY FENCE LINE
R-5
0
RAFFINATE PIT NO. 4
Control Road
0
R-1
RAFFINATE PIT NO. 3
0 R-4
0
R-2
RAFFINATE
PITS NO. 1+2
DOE FENCE LINE
0
R-3
ARMY FENCE LINE

Figure C-3

Weldon Spring Raffinate Pits Area

Table C-2. Surface area, volume, and content of the Weldon Spring Raffinate Pits

Pit	Constructed	Surface area (acres)	Total pit volume (yd^3)	Total waste volume (yd^3)	Percent filled	Total uranium content (kg)	Total thorium content (kg)
1	1958	1.2	18,500	17,400	94	9,100	--
2	1958	1.2	18,500	17,400	94	9,100	--
3	1959	8.4	166,700	129,600	78	91,000	500
4	1964	15.0	444,400	55,600	12	27,600	63,600
TOTALS		25.8	648,100	220,000		136,800	64,100

Source: Be83b

covers the residues in Pits 3 and 4. Pits 1 and 2 are usually covered by water as well, but evaporation during the summer months can leave the residues exposed.

The Quarry site (see Figure C-4), located about six kilometers southwest of the Raffinate Pits area, was initially used by the U.S. Army to dispose of TNT-contaminated rubble from the Weldon Spring Ordnance Works. The quarry was first used to dispose of radioactive wastes in 1959, when the AEC deposited thorium residues in drums. During 1963 and 1964, approximately 32,000 m^3 of uranium- and radium-contaminated building rubble, process equipment, and contaminated soil generated during the demolition of the Destrehan Street Feed Plant in St. Louis, were dumped in the quarry. In 1966, additional drummed and uncontained thorium residues were deposited when process equipment was removed from the Weldon Spring Chemical Plant. Additional TNT-contaminated stone and earth, disposed of later in 1966 by the Army, covers these thorium residues. The final deposits to the quarry were made in 1968 and 1969, when the Army's decontamination of the Chemical Plant generated approximately 4,600 m^3 of contaminated equipment and rubble. Table C-3 summarizes the radioactive wastes stored in the quarry.

Environmental monitoring in the vicinity of the two disposal areas includes a network of 15 radon monitors. Table C-4 summarizes the results of the WSS radon monitoring network during the period December 1981 - September 1982. The sampling locations of the monitors at the Raffinate Pits and the Quarry are shown in Figures C-3 and C-4, respectively. The off-site monitors are located north of the Raffinate Pits area. The results presented in Table C-4 are for total radon, including background.

The Middlesex Sampling Plant

The MSP, Middlesex, NJ, was used by the Manhattan Engineering District and the Atomic Energy Commission between 1943 and 1967, for sampling, weighing, assaying, and storing uranium and thorium ores. After termination of operations at the site in 1967, it was decontaminated and released to the U.S. Marine Corp for use as a training center. Radiological surveys of the site and nearby private properties discovered widespread contamination from windblown materials and use of material from the site as fill. The DOE took responsibility for the site and its cleanup. The cleanup, which was completed in 1982, consisted of recovering contaminated soils from off-site properties and removing contaminated soil areas from the site. All materials were consolidated in a storage pile on the southern portion of the site (see Figure C-5).

The temporary storage pile at the site is approximately 91 meters by 121 meters and 1.7 meters high. More than 31,000 metric tonnes of contaminated soil are contained in the pile. The average radium

Table C-3. Radioactive wastes stored in Weldon Spring Quarry

	Date deposited	Volume yd^3	Radioactive materials (kg)	Comments
3.8 percent thorium residues	1959	185	4,500	Drummed residues; volume estimated; most of the residues below quarry water; principal source of radioactivity: radium-228.
Destrehan Street Plant demolition rubble	1963-1964	50,000	--	Contaminated equipment, building rubble, estimate of uranium and thorium content not available; principal source of radioactivity: radium-226.
3 percent thorium residues	1966	555	11,800	Drummed residues; volume estimated; stored above water level; principal source of radioactivity: radium-228.
Weldon Spring Chemical Plant rubble	1968-1969	5,555	--	Contaminated equipment, building rubble; uranium and thorium content and radioactivity not available; principal sources of radioactivity: radium-226 and radium-228.
TOTALS:		56,295	16,300	

Table C-4. Radon concentrations at the Weldon Spring site, 1982

Sampling location[a]	December 1981-March 1982 (pCi/l)	April 1982-September 1982 (pCi/l)	Average (pCi/l)
R-1	0.58	0.53	0.56
R-2	0.35	0.55	0.45
R-3	0.27	0.26	0.27
R-4	0.30	0.16	0.23
R-5	0.84	0.24	0.54
R-6	0.40	0.32	0.36
R-7	0.48	1.03	0.76
R-8	0.86	0.92	0.89
R-9	1.07	1.55	1.31
R-10	0.30	0.52	0.41
R-11	0.51	0.47	0.49
R-12	0.12	0.13	0.13
R-13	0.25	0.30	0.28
R-14	0.23	0.18	0.21
R-15	0.15	0.41	0.28

Source: Be83b

(a) Sampling locations R-1 through R-5 are at the boundary of the Raffinate Pits area, R-6 through R-11 are at the boundary of the Quarry area, and R-12 through R-15 are off-site, north of the Raffinate Pits area.

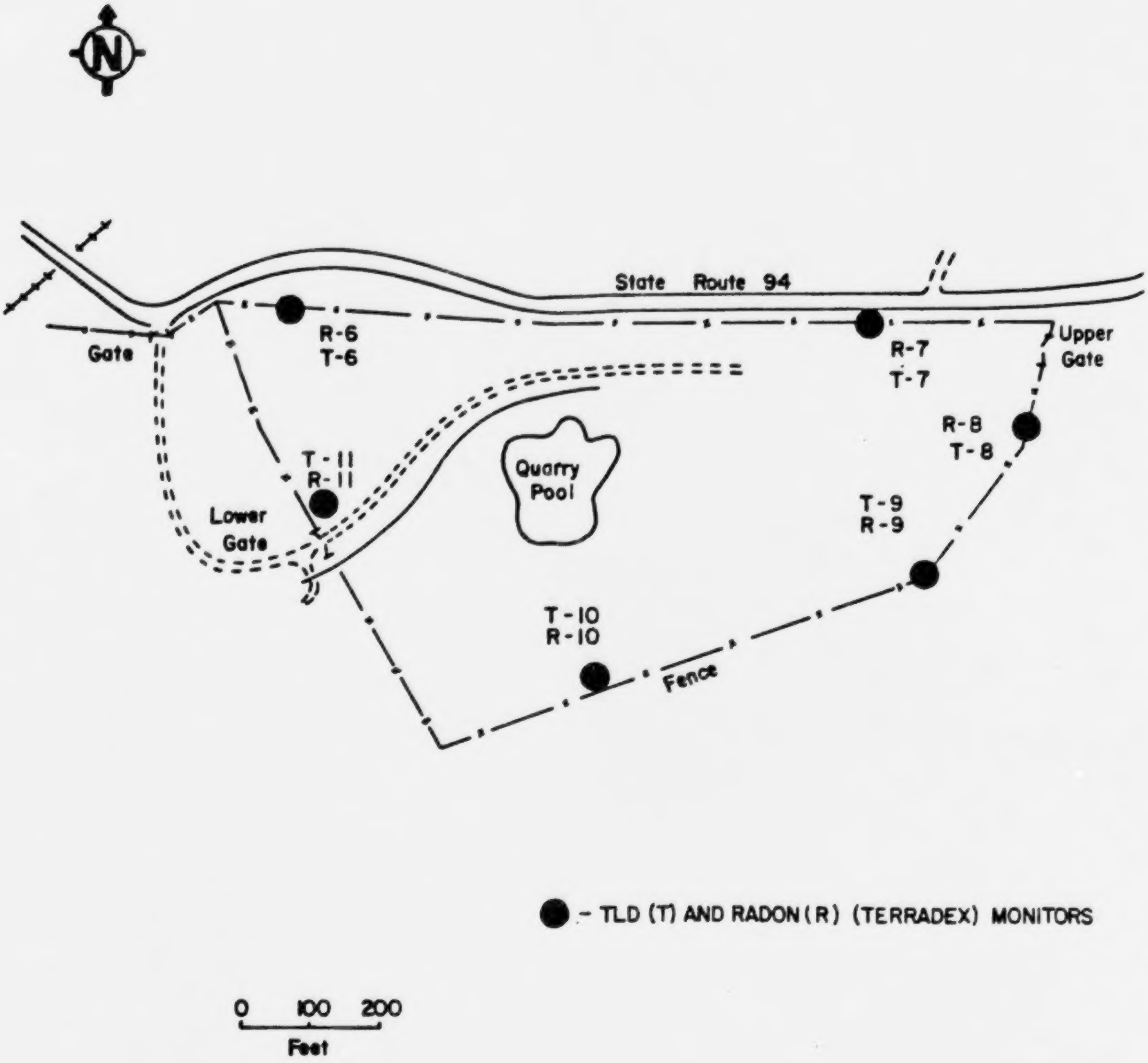

N
State Route 94
Gate
R-6
T-6
R-7
T-7
Upper
Gate
R-8
T-8
T-11
R-11
Quarry
Pool
Lower
Gate
T-9
R-9
T-10
R-10
Fence
● - TLD (T) AND RADON (R) (TERRADEX) MONITORS
0 100 200
Feet

Figure C-4

Weldon Spring Quarry site

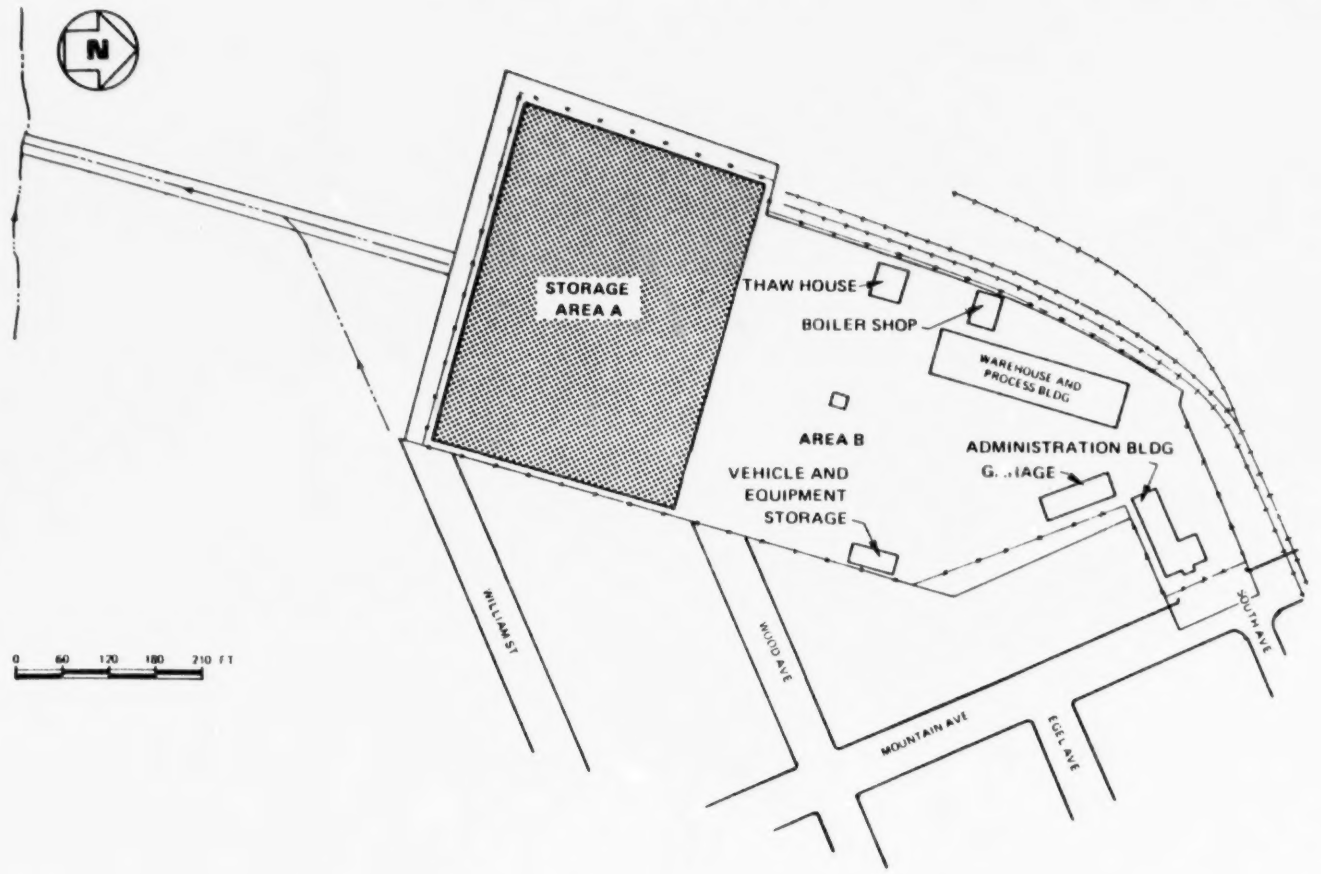

N
STORAGE AREA A
THAW HOUSE
BOILER SHOP
WAREHOUSE AND PROCESS BLDG
AREA B
ADMINISTRATION BLDG
GARAGE
VEHICLE AND EQUIPMENT STORAGE
WILLIAM ST
WOOD AVE
MOUNTAIN AVE
EGEL AVE
SOUTH AVE
0
60
120
180
210 FT

Figure C-5
The Middlesex Sampling Plant

concentration is estimated to be 79 pCi/g, so that there are about 2.5 curies of ^{226}radium in the pile. The pile is covered with a hyplon cover, which serves both to stabilize the pile and reduce the radon flux from the wastes. The radon flux from the pile, with cover installed, is estimated to be 8.4 pCi/m^2-sec (Fo79).

No monitoring data for the MSP were found. Given the proximity of the waste pile to the site boundary, and the estimated radon flux from the pile, it is possible that radon concentrations exceed background at the site boundaries. Based on calculated concentrations presented in the environmental statement for inactive mill tailings sites (EPA82), we estimate that boundary concentrations at the MSP could be as high as 0.5 - 0.7 pCi/l.

The Monticello Uranium Mill Tailings Pile

The Monticello Uranium Mill Tailings Pile (MUMT) is located at Monticello, Utah, and has been inactive since 1960. About 900,000 tons of uranium mill tailings were impounded in four separate areas covering about 40 acres total. The mill was purchased by the Federal Government in 1948 and operated by the AEC to recover uranium from 1949 to January 1960 when it was permanently shutdown. The Government owns the tailings site. In addition, some offsite contaminated properties at Monticello are included under DOE's FUSRAP program (see Appendix B). Uranium ore was processed by both acid and carbonate leaching and thus the tailings exhibit properties of both of these processes (Ab83, AEC63, AEC66, BFEC76).

The tailings were stabilized in 1961 by grading and leveling the tailings and the dikes made of tailings. The tailings were then covered with about one foot of pit run gravel and dirt, followed by one foot of top soil which was seeded with local vegetation (AEC63). Further demolition and decontamination activities were conducted in 1974 and 1975 to reduce radiation levels at the site and improve the esthetic quality (BFEC76).

Radiation measurements at the site were primarily for external gamma radiation. These levels were reduced by stabilization to a range of 2 to 3 about background levels. Radon emission measurements ranged from 175 to 675 pCi/m^2-sec for the 4 areas covered by tailings (Ab83). EPA estimated the total radon emissions from the pile using methods described in EPA83. It was assumed the ore processed at the site averaged 0.2 percent uranium, which was typical for ore processing during the 1950's. Thus, the radium content is 560 pCi/g tailings. For the 40-acre site with 2 feet of cover materials, the annual emission of radon is about 2800 Ci. The cover material is not effective in retaining radon, according to an analysis by Rogers (Ro81).

DOE REFERENCES

Ab83 Abramiuk I. N., et al., Monticello Remedial Action Project Site Analysis Report, Grand Junction Operations, GJ-10(83), Draft, November 1983.

AEC63 U.S. Atomic Energy Commission, Erosion Control, Uranium Mill Tailings Project, Monticello, Utah. Grand Junction Office, December 20, 1963.

AEC66 U.S. Atomic Energy Commission, Supplement to the Report of the Monticello Mill Tailings Erosion Control Project, Monticello, Utah. Grand Junction Office, Supplement to RMO-3005, April 20, 1966.

Ba81 Battelle Columbus Laboratories, A Comprehensive Characterization and Hazard Assessment of the DOE-Niagara Falls Storage Site, BMI-2074 REV., Columbus, OH, June 1981.

Ba84 Telephone conversation with Mr. J. Baublatz, U.S. DOE, Surplus Facilities Management Office, January 1984.

Be82 Bechtel National, Inc., Niagara Falls Storage Site (NFSS): Environmental Monitoring Report, Calendar Year 1981, 10-05-202-001, Oak Ridge, TN, May 1982.

Be83a Bechtel National, Inc., Niagara Falls Storage Site (NFSS): Environmental Monitoring Report, Calendar Year 1982, 10-05-202-002, Oak Ridge, TN, May 1983.

Be83b Bechtel National, Inc., Weldon Spring Site (WSS): Environmental Monitoring Report, Calendar Year 1982, 10-05-201-002, Oak Ridge, TN, June 1983.

BFEC76 Bendix Field Engineering Corporation, Uranium Ore Stockpile Site Decontamination and Mill Site Foundation Removal, Monticello, Utah. BFEC-1976-7, June 1976.

EPA82 U.S. Environmental Protection Agency, Final Environmental Impact Statement for Remedial Action Standards for Inactive Uranium Processing Sites (40 CFR 192), EPA 520/4-82-013, Vol. 1, October 1982.

EPA83 U.S. Environmental Protection Agency, Final Environmental Impact Statement for Standards for the Control of Byproduct Materials from Uranium Ore Processing (40 CFR 192), EPA 520/1-83-008-1, Vol. 1, September 1983.

DOE REFERENCES (Continued)

Fo79 Ford, Bacon and Davis Utah, Inc., Environmental Analysis of the Former Middlesex Sampling Plant and Associated Properties, Middlesex, New Jersey, FBDU 230-005, Salt Lake City, UT, April 1979.

NL082 National Lead of Ohio, Inc., Feed Materials Production Center: Environmental Monitoring Annual Report for 1981, NLCO-1180, Cincinnati, OH, May 1981.

Ro81 Rogers V. C. and G. M. Sandquist, Long-Term Integrity of Uranium Mill Tailings Covers, Report to the Nuclear Regulatory Commission, RAE-21-1 (Rev. 1), August 1981.

St83 Telephone Conversation with Mr. S, Stief, Safety Division, Oak Ridge National Laboratory, December 1983.

C.2 Nuclear Regulatory Commission Source Material Licensees

Facilities that could have potentially significant radon emissions are those which process material containing greater than 0.05 percent by weight of uranium or thorium (source material). Such facilities are required to be licensed by the Nuclear Regulatory Commission. The NRC has licensed more than five hundred facilities to possess and use source material. We relied on information provided by personnel in the NRC's Material Licensing Branch to identify facilities with potentially significant radon emissions. Listed below are the six facilities so provided.

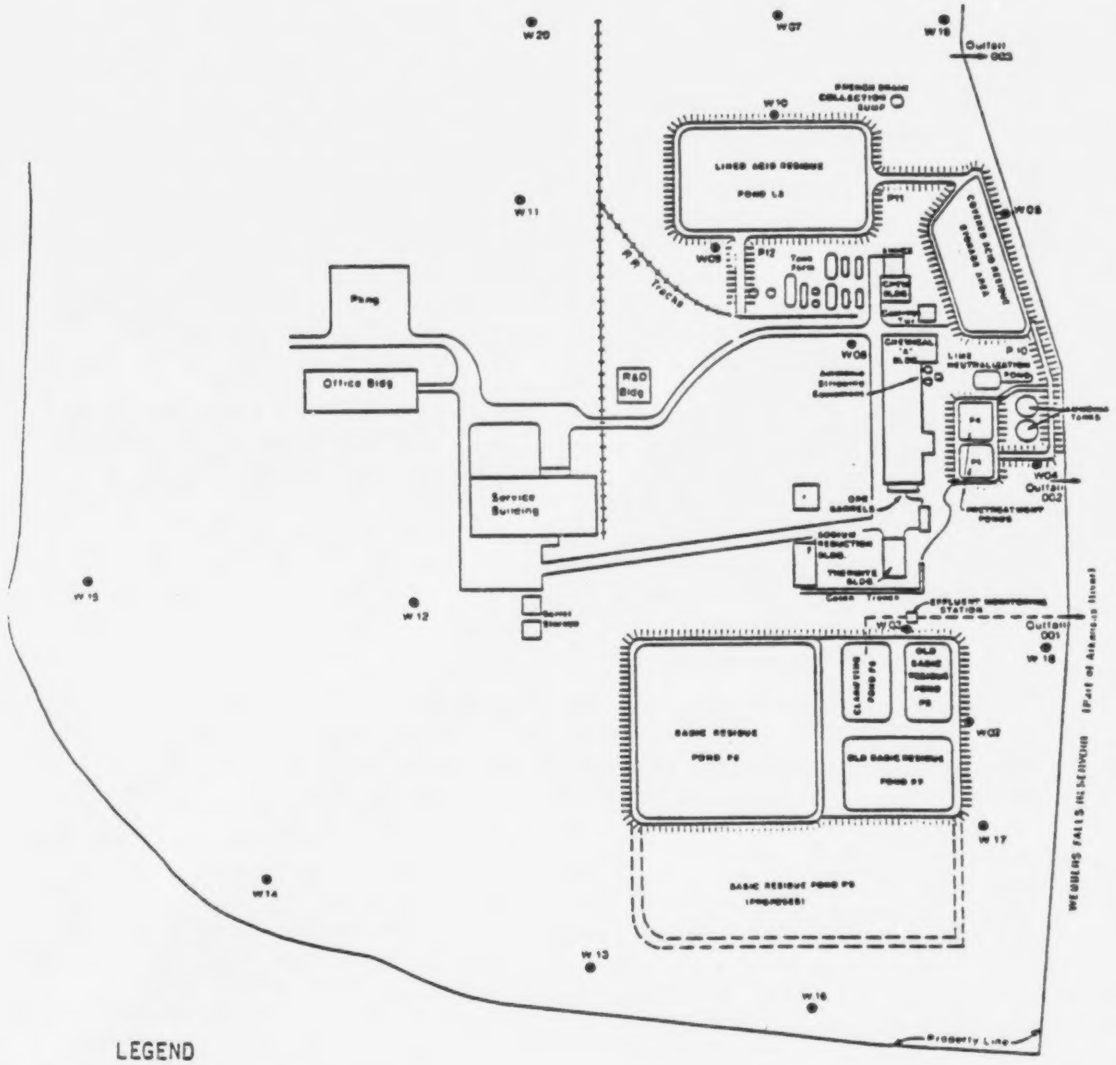
Facility	Licensed Amount of Source Material
Fansteel, Inc. Muskogee, Oklahoma	30 MT 0.1% U 67 MT 0.22% Th
Molycorp York, Pennsylvania	45 MT Natural Th 0.1 MT Natural U
Stepan Chemical Maywood, New Jersey	9500 yd^3 0.1% Th 8600 yd^3 0.1% Th
Vistron Corp. Lima, Ohio	15 MT U_3O_8 plus catalysts containing 50 MT U
Kerr-McGee Rare Earths Facility West Chicago, Illinois	1400 MT ThO_2 20 MT U_3O_8
Mallinckrodt Co. St. Louis, Missouri	27.1 MT U in Natural and Synthetic Ores 30 MT Th in Natural and Synthetic Ores

The dockets for each of these facilities were examined. However, only a limited amount of information on radon emissions from these sites was found. Each is described below.

Fansteel, Inc.

The Fansteel Metals Plant is on a 110-acre site near Muskogee, Oklahoma. Raw materials are processed to extract tantalum and columbium, and the liquid residues containing uranium and thorium are pumped to settling ponds where the solids settle out and the liquid is processed and disposed of. The site layout is shown in Figure C-6. There is no scale shown on Figure C-6; however, the proposed basic

AUG 15 1983


W20
W07
W19
Outfall 003
French Drain Collection Sump
W10
Lined Acid Residue Pond L3
P11
Covered Acid Residue Storage Area
W06
W09
P12
Tank Farm
R R Tracks
W11
Pond
Office Bldg
R&D Bldg
Service Building
W08
Chemical "A" Bldg.
Ammonia Stripping Equipment
Lime Neutralization Pond
P10
Tanks
W04
Outfall 002
Pretreatment Ponds
Ore Barrels
Sodium Reduction Bldg.
Thermite Bldg
Effluent Monitoring Station
W03
Outfall 001
W18
W15
W12
Clarifying Pond
Old Basic Residue Pond
Basic Residue Pond
W02
Old Basic Residue Pond
W17
Basic Residue Pond (Proposed)
W14
W13
W16
Property Line

LEGEND

L: Total Retention Lagoons
(listed in Appendix A)
P: Treatment Ponds
(listed in Appendix B)
W: Ground Water Monitoring Location

Figure C-6

residue pond toward the bottom is 570 feet long (east to west) by 277 feet wide (north to south) measured from the inside top of the dikes. The facility is licensed to possess no more than 30 MT of natural uranium and 67 MT of natural thorium. We could not determine how much material is actually on hand; however, the licensee requested approval in March 1983 to construct the proposed pond shown on Figure C-6 because pond 8 (to the northwest of the proposed pond) will be full within two years.

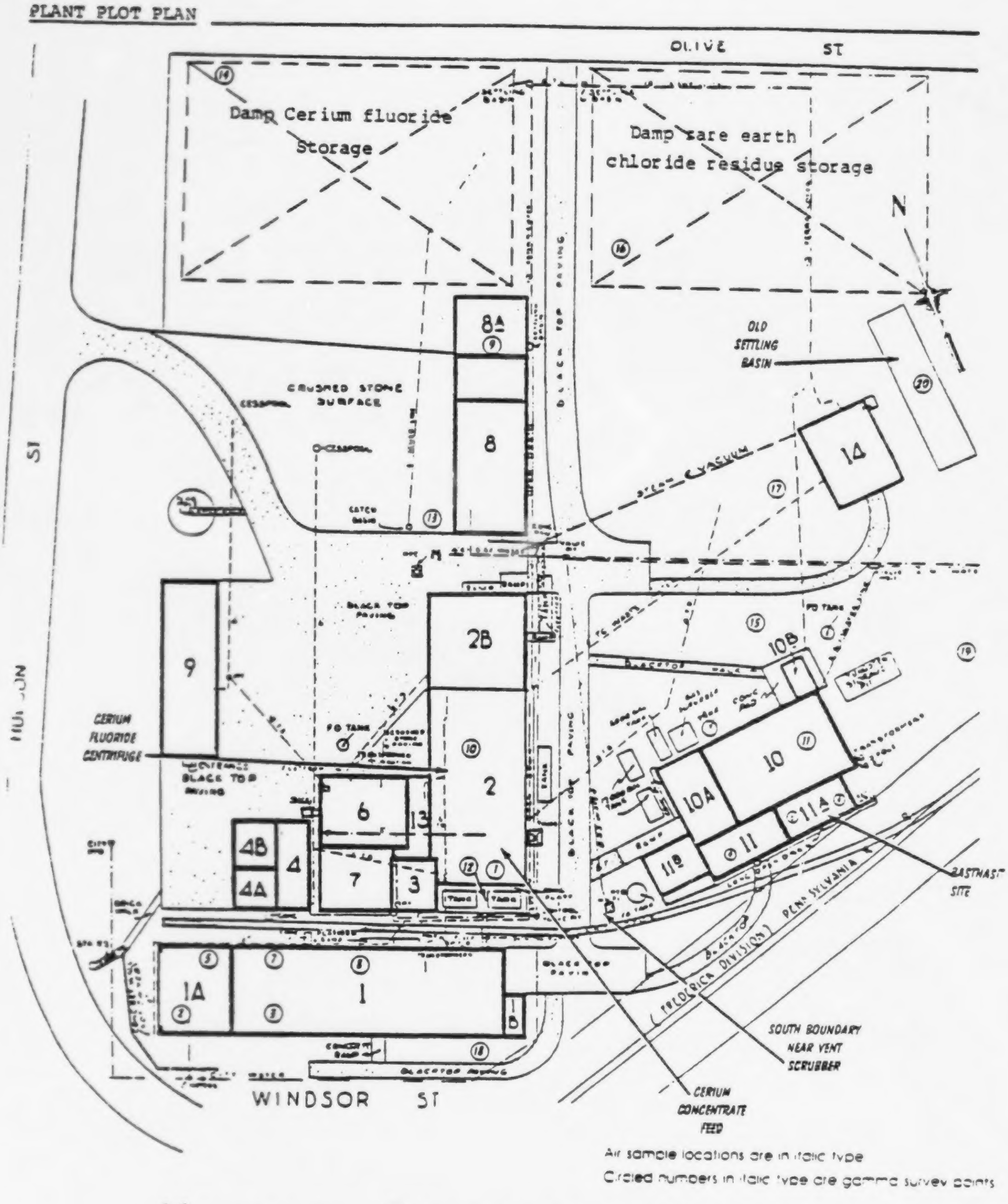
Molycorp

The Molycorp plant at York, Pennsylvania (site layout shown in Figure C-7), operates a rare earth extraction process which produces about 26 MT/month (dry weight) of residues containing 0.65 wt% thorium and 0.002 wt% uranium. These residues are currently put into 55-gallon, plastic-bag-lined, steel drums pending future disposal. Apparently there are plans to approximately double production. Current plans for disposal of the residues call for them to be added to the tailings being disposed of at a Nuclear Regulatory Commission licensed tailings impoundment at Sweetwater, Wyoming. A measurement at the south plant boundary, near the vent scrubber, indicates a radon concentration of 0.002-0.003 working levels.

In addition to these residues, which are apparently going to be disposed of, there was reference to about 800 cubic yards of contaminated earth at the York plant, and a thorium slag waste pile at a Washington, Pennsylvania, facility. We could not obtain information on these potential sources of radon, apart from one statement that the radiation level at the surface of the contaminated earth at the York plant was as high as 580 μR per hour (5R per year).

2.3 Stepan Chemical

Stepan Chemical does not use source material; however, its plant is on land formerly owned by the Maywood Chemical Company, who between 1895 and 1959 operated a process which resulted in thorium waste. Because there were no restrictions on disposal of such waste during this period, it was simply put in piles at various places on the Maywood Chemical Co. property, some of which was later sold. The site and some of the surrounding property (including some residential property) have been found to be contaminated with thorium. The Nuclear Regulatory Commission is presently negotiating with Stepan Chemical regarding the steps to be taken to clean up the area. The plant site, along with measured radiation levels in μR/hour, is shown in Figure C-8. Apparently there are (according to the license) about 8600 cubic yards of 0.25% thorium residues buried in the area identified as "Burial III" on Figure C-8. No information was available regarding the amounts in other (off-site) areas. The Nuclear Regulatory Commission has stated that the off-site contamination does not pose any immediate threat to public health and safety. The Nuclear Regulatory Commission


PLANT PLOT PLAN
OLIVE ST
Damp Cerium fluoride Storage
Damp rare earth chloride residue storage
N
OLD SETTLING BASIN
CRUSHED STONE SURFACE
CESSPOOL
CATCH BASIN
BLACK TOP PAVING
HUDSON ST
CERIUM FLUORIDE CENTRIFUGE
FO TANK
STEAM VACUUM
1
2
2B
3
4
4A
4B
6
7
8
8A
9
10
10A
10B
11
11A
11B
13
14
1A
1B
⑤
②
⑦
③
⑧
⑨
⑩
⑪
⑫
①
⑬
⑭
⑮
⑯
⑰
⑱
⑲
⑳
㉑
TANK
PENNSYLVANIA
FREDERICK DIVISION
BLACKTOP PAVING
WINDSOR ST
BASTNASITE SITE
SOUTH BOUNDARY NEAR VENT SCRUBBER
CERIUM CONCENTRATE FEED

Air sample locations are in italic type

Circled numbers in italic type are gamma survey points

MOLYBDENUM CORPORATION OF AMERICA

YORK, PENNSYLVANIA

1942 - 6/5/1968

Figure C-7

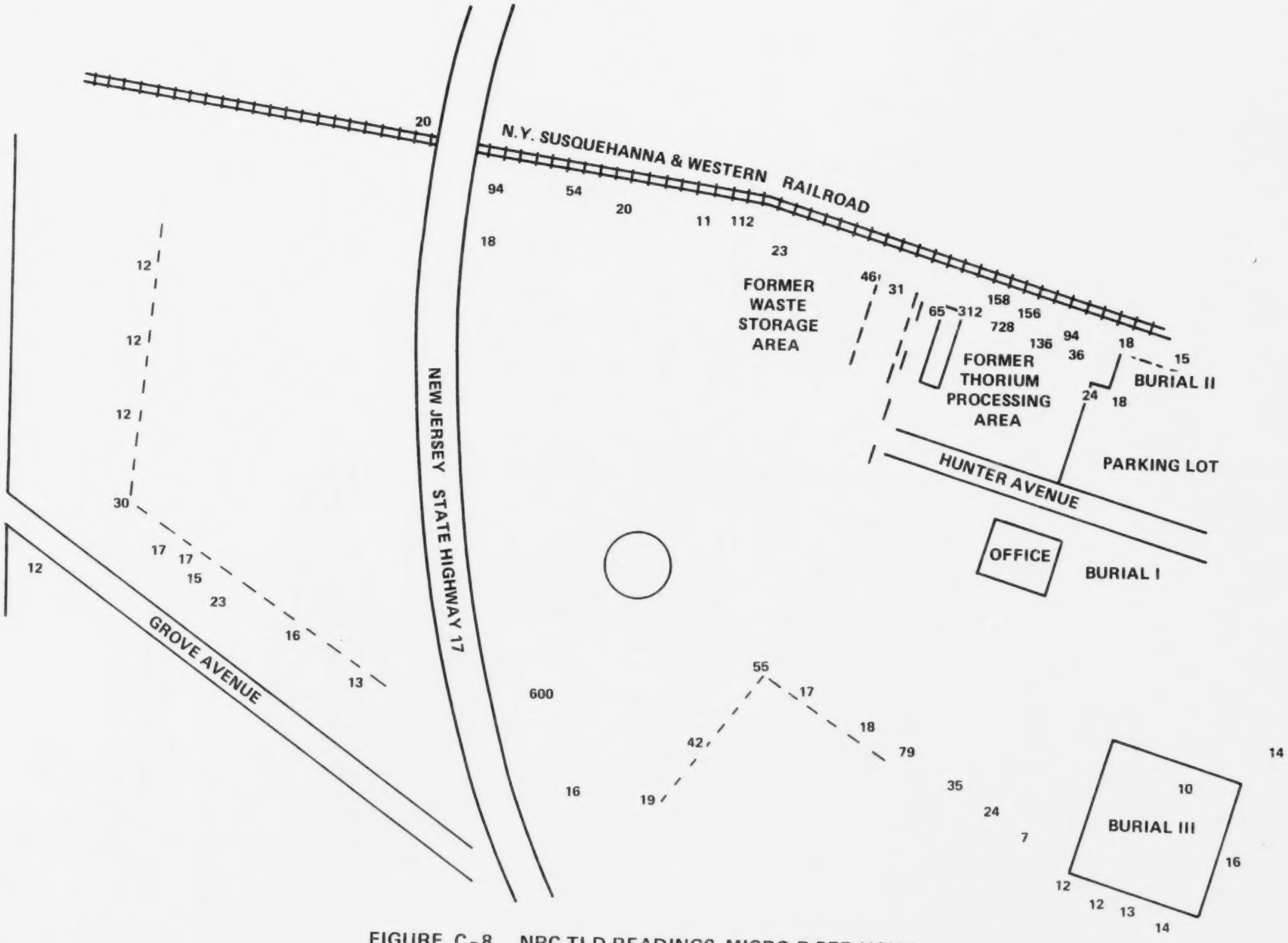

N.Y. SUSQUEHANNA & WESTERN RAILROAD
NEW JERSEY STATE HIGHWAY 17
GROVE AVENUE
HUNTER AVENUE
FORMER WASTE STORAGE AREA
FORMER THORIUM PROCESSING AREA
BURIAL II
PARKING LOT
OFFICE
BURIAL I
BURIAL III
20
94
54
20
11
112
18
23
46
31
65
312
158
728
156
136
94
36
18
15
24
18
12
12
12
30
17
17
15
23
16
13
12
600
16
19
42
55
17
18
79
35
24
7
14
10
16
12
12
13
14

FIGURE C-8. NRC TLD READINGS, MICRO-R PER HOUR MARCH 24 TO MAY 21, 1981 has noted that there is a potential for a few persons living in some of the residences to receive radiation doses in excess of the accepted limits for members of the public.

Vistron Corporation

Vistron at one time manufactured uranium-bearing catalysts but does not do so any longer. As of 1976, 420 MT of catalysts containing about 50 MT of uranium and about 15 MT of U_3O_8 were stored in the Vistron Plant. This material is stored in sealed drums in an abandoned warehouse on the plant site. The measured radiation level at one foot from the surface of these drums was 0.4 mrem/hr for the drums containing catalysts and 1.1 mrem/hr for the drums containing U_3O_8.

Kerr-McGee

Liquid waste from the production of thorium and rare earth elements was generated at the West Chicago site from 1932 to 1973. The site layout is shown in Figure C-9. Plans for its decommissioning are currently underway. The Nuclear Regulatory Commission, in its final environmental statement related to the decommissioning (NUREG-0904, May 1983), recommended that all radioactive material be stabilized and stored on-site for an indefinite period, with ultimate disposal to be determined later. The amounts of ThO_2 and U_3O_8 are as shown below:

Location	Quantity, MT ThO_2	U_3O_8
Ore residue pile	210	3
Sediment pile (near Building 18)	470	6
Ponds 1-3	760	12

The Nuclear Regulatory Commission has estimated current releases to be 70 Ci/yr of radon-222 and 14,000 Ci/yr of radon-220, and doses of <1 mrem/yr to the whole body, 4 mrem/yr to the bone, 25 mrem/yr to the lung, and 260 mrem/yr to the bronchial epithelium of the nearest resident. With the recommended action, these doses would be reduced to zero.

Mallinckrodt Company

The Mallinckrodt Company's columbium-tantalum processing facility in St. Louis, Mo., is licensed to possess 27.1 MT of uranium and 30 MT of thorium in natural and synthetic ores. The docket for this facility (40-6563) does not contain information on the layout of the facility or the location of the uranium and thorium ore storage areas at the site. Nor does the docket contain data on radon emissions or boundary

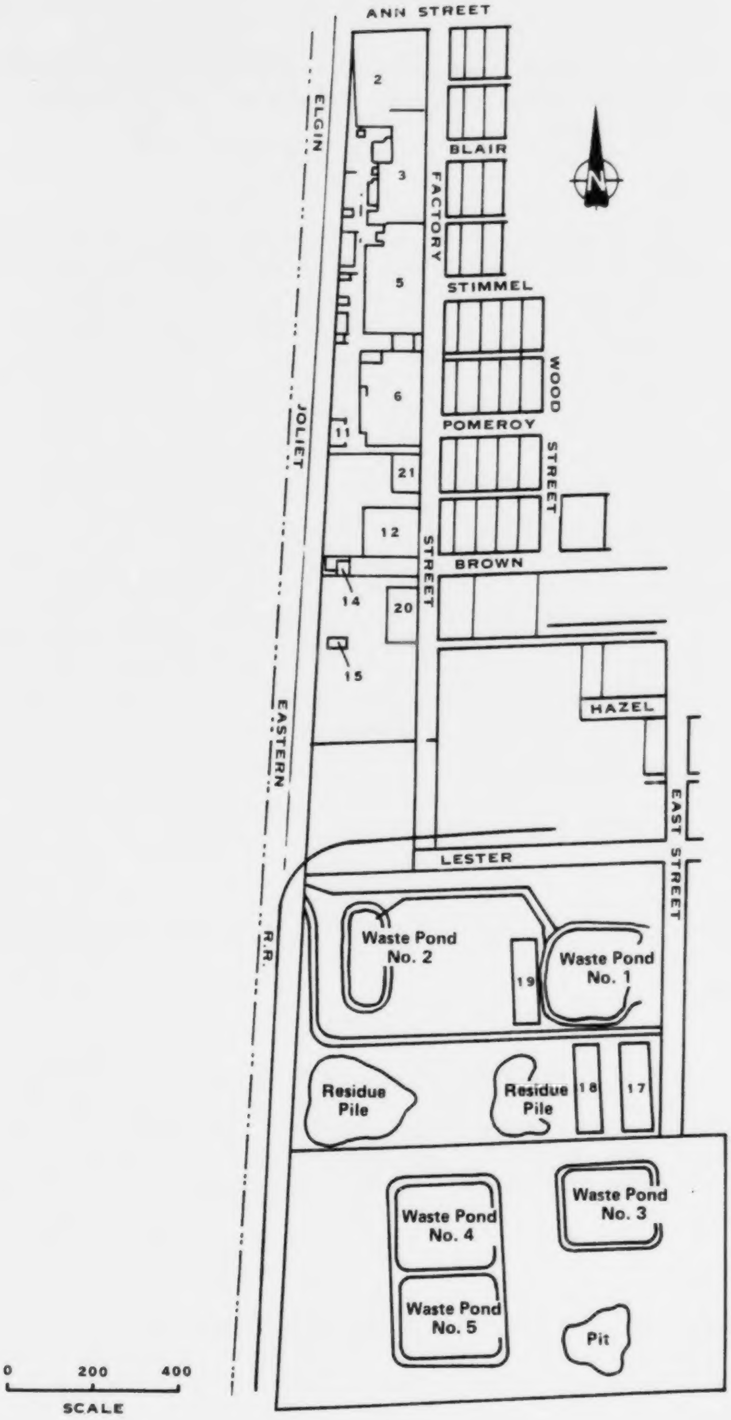

ANN STREET
BLAIR
FACTORY
STIMMEL
WOOD
POMEROY
STREET
BROWN
STREET
HAZEL
EAST STREET
LESTER
ELGIN
JOLIET
EASTERN
R.R.
2
3
5
6
11
21
12
14
20
15
Waste Pond No. 2
Waste Pond No. 1
19
Residue Pile
Residue Pile
18
17
Waste Pond No. 3
Waste Pond No. 4
Waste Pond No. 5
Pit
N
0
200
400
SCALE

FIGURE C-9. DIAGRAM OF THE KERR-McGEE FACILITY
Adapted from ER. Figure 2.5.1.

concentrations. Our attempts to obtain such information from the NRC (both from headquarters and the cognizant regional office) were unsuccessful. Estimates of the actual amounts of material stored at the site or of the radon emissions from the materials are not available.

NRC REFERENCES

The following documents were used in preparing the NRC section of this report and are available for inspection in the NRC Public Document Room under the appropriate docket number.

1. Fansteel, Inc. (Docket 40-7580)

   USNRC, Draft Safety Evaluation Report Related to New Waste Treatment Pond No. 9, 1983.

2. Molycorp (Docket 40-8794)

   Application for source material license, 1981.

   Eberline Instrument Corp. report of Radiation Survey of Molycorp Plant at York, Pennsylvania, 1981.

   Molycorp Response to NRC Notice of Violation, 1981.

3. Stepan Chemical (Docket 40-8610)

   NRC Report on Thorium Contamination in the Area of Maywood and Rochelle Park, New Jersey, 1981.

4. Vistron Corp. (Docket 40-7604)

   Letter from R.C. Shower (Vistron) to J.M. Bell (NRC), February 24, 1976.

   Letter from G.K. Doss (Vistron) to K.S. Dragonette (NRC), January 13, 1976.

5. Kerr McGee (Docket 40-2061)

   USNRC, Final Environmental Statement Related to the Decommissioning of the Rare Earths Facility, West Chicago, Illinois, NUREG-0904, May 1983.

6. Mallinckrodt Company (Docket 40-6563)

APPENDIX D

APPENDIX D

DEPARTMENT OF ENERGY GOCO FACILITIES*

(Government-Owned, Contractor-Operated Facilities) where contractors are subject to DOE Procurement Regulation 9-50.704-2(a)

California

			Responsible Field Office
1.	a.	Lawrence Berkeley Laboratory University of California Berkeley, California	SAN
	b.	Donner Laboratory University of California Berkeley, California	SAN
	c.	Chemical Biodynamics Laboratory University of California Berkeley, California	SAN
	d.	Dymo Facility (Building 934) University of California Berkeley, California	SAN
		Principal Contractor: University of California Berkeley, California 94720	
2.	a.	Lawrence Livermore Laboratory University of California End of East Avenue Livermore, California	SAN
	b.	Lawrence Livermore Laboratory - Site 300 17 miles east of Livermore on Corral Hollow Road Livermore, California	SAN
		Principal Contractor: University of California P.O. Box 808 Livermore, California 94550	

---

*See key to abbreviations on page D-21.

Preceding page blank

Responsible
Field Office

California (continued)

3. Sandia Laboratories, Livermore — AL
End of East Avenue
Livermore, California

Principal Contractor:
Western Electric, Inc.
Livermore, California 94550

4. 130 Robin Hill Road — NV
Goleta, California

Principal Contractor:
EG&G, Inc.
130 Robin Hill Road
Goleta, California 93017

5. a. Energy Technology Engineering Center — SAN
DOE Triangle at Santa Susana
Canoga Park, California

b. Energy Technology Engineering Center — SAN
Two DOE-owned buildings, total about
5,000 square feet, outside DOE triangle
Canoga Park, California

Principal Contractor:
Rockwell International
Atomics International Division
P.O. Box 1449
Canoga Park, California 91304

6. Stanford Linear Accelerator Center — SAN
2572 San Hill Road
Menlo Park, California

Principal Contractor:
Stanford University
P.O. Box 4349
Stanford, California 94305

7. 2801 Old Crow Canyon Road — NV
San Ramon, California

Principal Contractor:
EG&G, Inc.
P.O. Box 204
San Ramon, California 94583

Responsible Field Office

California (continued)

8. Research and Development Building, Project No. 37 — OR
2525 West 190th Street
Torrance, California

Principal Contractor:
AiResearch Manufacturing Company
A Division of Garrett Corporation
2525 West 190th Street
Torrance, California 90509

Colorado

1. Rocky Flats Plant — AL
25 miles northwest of Denver - Highway 93
Between Boulder and Golden, Colorado

Principal Contractor:
Rockwell International
Atomics International Division
P.O. Box 464
Golden, Colorado 80401

2. Solar Energy Research Institute — CH
Contract No. EG-77-C-01-4042
Golden, Colorado 80401

Principal Contractor:
Solar Energy Research Institute
1617 Cole Boulevard
Golden, Colorado 80401

3. DOE Compound — GJ
Grand Junction, Colorado

Principal Contractor:
Bendix Field Engineering Corporation
P.O. Box 1569
Grand Junction, Colorado

Connecticut

1. Knolls Atomic Power Laboratory — SNR
Windsor Site
Windsor, Connecticut

Responsible
Field Office

Connecticut (continued)

Principal Contractor:
General Electric Company
P.O. Box 545
Windsor, Connecticut 06095

Florida

1. Pinellas Plant — AL
5 miles southeast of Largo on Bryan Dairy
and Belcher Roads
St. Petersburg, Florida

Principal Contractor:
General Electric Company
P.O. Box 11508
St. Petersburg, Florida 33733

2. Sandia Laboratories Mobile and Remote Range Facility — AL
Building 1690
Cape Canaveral, Florida 32920

Principal Contractor:
Western Electric, Inc.
P.O. Box 5800
Albuquerque, New Mexico 87115

Hawaii

1. Sandia Laboratories — AL
Barking Sands, Kauai, Hawaii

Principal Contractor:
Western Electric, Inc.
P.O. Box 478
Waimea, Kauai, Hawaii 96796

2. Communications and Scientific Station — AL
Haleakala, Maui, Hawaii

Principal Contractor
Western Electric, Inc.
Pacific Area Support Office
P.O. Box 9186
Haleakala, Maui, Hawaii

Idaho

	Responsible Field Office
1. Idaho National Engineering Laboratory 40 miles west of Idaho Falls, on U.S. Highway 20	ID
Principal Contractors:	
EG&G Idaho, Inc.	ID
Argonne National Laboratory	CH
Exxon Nuclear Idaho Company, Inc.	ID
Westinghouse Electric Corporation	PNR
Resident Construction Contractor:	
Morrison-Knudsen Company, Inc.	ID
Project Construction Contractors:	
Jones-Boecon (J-B)	ID
Catalytic, Inc.	ID
2. Idaho Falls, DOE, Office Building 550 Second Street Idaho Falls, Idaho 83401	ID
3. Contractor Operated Facilities	
a. Computer Science Center 1155 Foote Drive Idaho Falls, Idaho 83401	ID
b. Computer Science Technical Support Building 1520 Sawtell Idaho Falls, Idaho 83401	ID
c. Technical Support Building Addition 1580 Sawtell Idaho Falls, Idaho 83401	ID
d. First Street Building 550 First Street Idaho Falls, Idaho 83401	ID
e. Idaho Falls Warehouse Building 3600 Bombardier Boulevard Idaho Falls, Idaho 83401	ID
f. Idaho Falls Library Building Basement 457 Broadway Idaho Falls, Idaho 83401	ID

Responsible
Field Office

Idaho (continued)

g. Idaho Geothermal - Raft River Project ID

Cassia County - approximately 50 miles southeast of Burley off U.S. 30 on approximately 5,000 acres of National Resource Land and other lands within the boundaries of DOE application for withdrawal filed with the BLM and assigned Serial Register No. I - 7435

Principal Contractor:
EG&G Idaho, Inc.
1955 Fremont
Idaho Falls, Idaho 83401

4. Willow Creek Office Building ID
1955 Fremont
Idaho Falls, Idaho 83401

Principal Contractors:
EG&G Idaho, Inc.
Exxon Nuclear Idaho Company, Inc.
Morrison-Knudsen Company, Inc.
Catalytic, Inc.

Illinois

1. Argonne National Laboratory CH
9700 South Cass Avenue
Argonne, Illinois 60439

Principal Contractor:
Argonne Universities Association
P.O. Box 307
Argonne, Illinois 60439

2. Fermi National Accelerator Laboratory CH
Off Kirk Road on West Boundary
Batavia, Illinois 60510

Principal Contractor:
University Research Associates, Inc.
2101 Constitution Avenue
Washington, D.C. 20037

Responsible
Field Office

Iowa

1. Ames Laboratory CH

    a. Reactor Building - Scholl Road
    b. Physics Addition Building
    c. Laboratory and Office Building
    d. Spedding Hall - Spammell Drive
    e. Metallurgy Building - Spammell Drive
    f. Metals Development - Spammell Drive
    g. Warehouse Building - Maintenance Area
    h. Mechanical Maintenance - Maintenance Area
    i. Painting and Air Conditioning Shop - Maintenance Area

Principal Contractor:
Iowa State University
Ames, Iowa 50011

Kentucky

1. Paducah Gaseous Diffusion Plant OR
Paducah, Kentucky

Principal Contractor:
Union Carbide Corporation
P.O. Box 1410
Paducah, Kentucky 42001

Maryland

1. DOE Headquarters Building HQ
Germantown, Maryland

Principal Contractor:
Calculon Corporation
c/o U.S. Department of Energy
Washington, D.C. 20545

Massachusetts

1. Bates Linear Accelerator CH
Middleton, Massachusetts

Principal Contractor:
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, Massachusetts 02139

	Responsible Field Office
Missouri	
1. Kansas City Plant Bannister Road and Troost Kansas City, Missouri	AL
Principal Contractor: The Bendix Corporation P.O. Box 1159 Kansas City, Missouri 64141	
2. Weldon Springs Retention Basin and Quarry Off U.S. Highway 70 West Weldon Springs, Missouri	OR
Principal Contractor: National Lead Company of Ohio P.O. Box 39158 Cincinnati, Ohio 45329	
Montana	
1. Magnetohydrodynamic, Component Development and Integration Facility 53.16 acres near the Butte Industrial Park, approximately 5 miles south of Butte, Montana	ID
Principal Contractor: Kaiser Engineers (Construction) Montana Energy Research and Development Institute (Operations) MHD Site Office, P.O. Box 3562 Butte, Montana 59701	
Nevada	
1. 2753 South Highland Avenue Las Vegas, Nevada	NV
Principal Contractors: Holmes & Narver, Inc. 2753 South Highland Avenue Las Vegas, Nevada 89114 Wackenhut Services, Inc. 2753 South Highland Avenue Las Vegas, Nevada 89114	

Responsible
Field Office

Nevada (continued)

Computer Sciences Corp.
2753 South Highland Avenue
Las Vegas, Nevada 89114

2. Nevada Test Site — NV
Mercury, Nevada

Principal Contractors:
Reynolds Electrical & Engineering Co., Inc.
P.O. Box 14400
Las Vegas, Nevada 89114

Westinghouse Electric Corporation/Advanced
Energy Systems Division
P.O. Box 327
Mercury, Nevada 89023

3. Tonopah Test Range — AL
47 miles southeast of Tonopah
Tonopah, Nevada

Principal Contractor:
Western Electric, Inc.
P.O. Box 871
Tonopah, Nevada 89049

4. a. 680 East Sunset Road — NV
Las Vegas, Nevada

b. 6367 Escondido Road — NV
Las Vegas, Nevada

Principal Contractor:
EG&G, Inc.
P.O. Box 1921
Las Vegas, Nevada 89101

5. a. 25 Wyandotte Street — NV
b. Las Vegas, Nevada

b. 2300 West Rancho Drive, Suite 216 — NV
Las Vegas, Nevada

c. 3084 South Highland Drive — NV
Building 6, 7, and 8
Las Vegas, Nevada

Responsible
Field Office

Nevada (Continued)

Principal Contractor:
Reynolds Electrical & Engineering Co., Inc.
P.O. Box 14400
Las Vegas, Nevada 89114

6. North Las Vegas Facility NV
316 East Atlas Circle
North Las Vegas, Nevada

Principal Contractor:
EG&G, Inc.
P.O. Box 1921
Las Vegas, Nevada 89101

New Jersey

1. Princeton Plasma Physics Laboratory CH
"C" Site and "A" Site on the Forrestal Campus
Princeton, New Jersey

Principal Contractor:
Princeton University
P.O. Box 682
Princeton, New Jersey 08540

2. Burns & Roe Services Corporation CH
Contract No. DE-AC02-79ET14850
Oradell, New Jersey 07649

Principal Contractor:
Burns & Roe Services Corporation
496 Kinderkamack Road
Oradell, New Jersey 07649

New Mexico

1. Sandia Laboratories, Albuquerque AL
Kirtland Air Force Base - East
Albuquerque, New Mexico

Principal Contractor:
Western Electric, Inc.
P.O. Box 5800
Albuquerque, New Mexico 87115

Responsible
Field Office

New Mexico (Continued)

2. Sandia Laboratories Mobile and Remote Range Facility — AL
Building 1137-1
White Sands Missile Range, New Mexico 88002

Principal Contractor:
Western Electric, Inc.
P.O. Box 5800
Albuquerque, New Mexico 87115

3. Inhalation Toxicology Research Institute — AL
Kirtland Air Force Base - East
Albuquerque, New Mexico

Principal Contractor:
Lovelace Medical Foundation
Building 9200, Area Y
KAFB - East
Albuquerque, New Mexico 87115

4. EG&G Operations — NV
Kirtland Air Force Base - West
NC-135 Area
Albuquerque, New Mexico

Principal Contractor:
EG&G, Inc.
c/o Nevada Site Manager
KAFB - West
P.O. Box 4339
Albuquerque, New Mexico 87106

5. Los Alamos Scientific Laboratory — AL
Los Alamos, New Mexico

Principal Contractor:
University of California
P.O. Box 1663
Los Alamos, New Mexico 87544

6. 1100 4th Street — NV
Los Alamos, New Mexico

Principal Contractor:
EG&G, Inc.
P.O. Box 809
Los Alamos, New Mexico 87544

		Responsible Field Office
7.	901 Trinity Drive Los Alamos, New Mexico Principal Contractor: The Zia Company 901 Trinity Drive Los Alamos, New Mexico 87544	AL
8.	Waste Isolation Pilot Plant 32 miles SE of Carlsbad Principal Contractor: Western Electric, Inc. 1502 West Stevens Street Carlsbad, New Mexico 88220	AL
9.	Fenton Hill Geothermal Site - TA-57 45 miles west of Los Alamos Principal Contractor University of California P.O. Box 1663 Los Alamos, New Mexico 87544	AL
10.	Ross Aviation Albuquerque Sun Port Albuquerque, New Mexico Principal Contractor: Ross Aviation, Inc. P.O. Box 9124 Albuquerque, New Mexico 87119	AL

New York

1.	Brookhaven National Laboratory Off William Floyd Parkway Upton, New York Principal Contractor: Associated Universities, Inc. Upton, New York 11973	CH
2.	Knolls Atomic Power Laboratory River Road Niskayuna, New York Principal Contractor: General Electric Company P.O. Box 1072 Schenectady, New York 12301	SNR

	Responsible Field Office
New York (continued)	
3. Knolls Atomic Power Laboratory Kesselring Site West Milton, New York Principal Contractor: General Electric Company P.O. Box 1072 Schenectady, New York 12301	SNR
4. Niagara Falls Boron Plant Model City, New York Principal Contractor: National Lead Company of Ohio P.O. Box 39158 Cincinnati, Ohio 45329	OR
Ohio	
1. Portsmouth Gaseous Diffusion Plant Off Highway U.S. 23 Piketon, Ohio Principal Contractor: Goodyear Atomic Corporation P.O. Box 628 Piketon, Ohio 45661	OR
2. Mound Facility Miamisburg, Ohio Principal Contractor: Monsanto Research Corporation P.O. Box 32 Miamisburg, Ohio 45342	AL
3. Feed Materials Production Center 6 miles north of Cincinnati - off Highway U.S. 50 bypass west Fernald, Ohio Principal Contractor: National Lead Company of Ohio P.O. Box 39158 Cincinnati, Ohio 45239	OR

Responsible
Field Office

Pennsylvania

1. Bettis Atomic Power Laboratory — PNR
West Mifflin, Pennsylvania

Principal Contractor:
Westinghouse Electric Corporation
P.O. Box 79
West Mifflin, Pennsylvania 15122

2. Pittsburgh Energy Technology Center — CH
4800 Forbes Avenue
Pittsburgh, Pennsylvania 15213

Principal Contractor:
General Electric Company
MATSCO
P.O. Box 7507
Philadelphia, Pennsylvania 19101

3. Shippingport Nuclear Power Station — PNR
Shippingport, Pennsylvania

Principal Contractor:
Duquesne Light Company
P.O. Box 57
Shippingport, Pennsylvania 15077

South Carolina

1. Savannah River Plant — SR
18 miles south of Aiken on State Route 125
Aiken, South Carolina

Principal Contractors:
E.I. du Pont de Nemours and Company
Aiken, South Carolina 29801

University of Georgia
Drawer E
Aiken, South Carolina 29801

Tennessee

1. Oak Ridge National Laboratory — OR
Bethel Valley Road - About 12 miles
from Oak Ridge
Oak Ridge, Tennessee

Responsible
Field Office

Tennessee (continued)

1. Oak Ridge National Laboratory (continued)

Principal Contractor:
Union Carbide Corporation
P.O. Box X
Oak Ridge, Tennessee 37830

2. Y-12 Plant — OR
Bear Creek Road - About 1.5 miles
from Oak Ridge
Oak Ridge, Tennessee

Principal Contractor:
Union Carbide Corporation
P.O. Box Y
Oak Ridge, Tennessee 37830

3. Oak Ridge Gaseous Diffusion Plant — OR
Oak Ridge Turnpike - About 8 miles
from Oak Ridge
Oak Ridge, Tennessee

Principal Contractor:
Union Carbide Corporation
P.O. Box P
Oak Ridge, Tennessee 37830

4. Comparative Animal Research Laboratory — OR
1299 Bethel Valley Road
Oak Ridge, Tennessee

Principal Contractor:
University of Tennessee
P.O. Box 1071
Knoxville, Tennessee 37901

5. a. New Museum — OR
Tulane Avenue
Oak Ridge, Tennessee

b. Medical Division Complex — OR
Vance Road
Oak Ridge, Tennessee

c. Atmospheric Turbulence and Diffusion Laboratory — OR
South Illinois
Oak Ridge, Tennessee

Responsible
Field Office

Tennessee (continued)

Oak Ridge National Laboratory (continued)

d. Warehouse Bays 4, 5 and part of 3 of — OR
Building 1918-T2
Warehouse Road
Oak Ridge, Tennessee

e. Special Training Division — OR
Building 2714 (F, G, and Annex) and 2715
Laboratory Road
Oak Ridge, Tennessee

Principal Contractor:
Oak Ridge Associated Universities
P.O. Box 117
Oak Ridge, Tennessee 37830

6. a. Water Treatment Facilities — OR
Oak Ridge, Tennessee

b. Building 1916-T2
Warehouse Road
Oak Ridge, Tennessee

Principal Contractor:
The Rust Engineering Company
P.O. Box 587
Oak Ridge, Tennessee 37830

7. Charlotte Hall and Cheyenne Hall — OR
Oak Ridge Turnnpike
Oak Ridge, Tennessee 37830

Principal Contractor:
Union Carbide Corporation
P.O. Box Y
Oak Ridge, Tennessee 37830

Texas

1. Pantex Plant — AL
21 miles northeast of Amarillo, 2 miles north of U.S. Highway 60
Amarillo, Texas

Principal Contractor:
Mason & Hanger - Silas Mason Co., Inc.
P.O. Box 647
Amarillo, Texas 79177

Responsible
Field Office

Washington

1. Solvent Refined Coal Pilot Plant — OR
Fort Lewis, Washington 98433

2. Hanford Project — RL
5 miles north of Richland Federal Building
Richland, Washington
    Principal Contractors:
    Rockwell International
    Rockwell Hanford Operations
    P.O. Box 250
    Richland, Washington 99352

    Battelle-Pacific Northwest Laboratory
    P.O. Box 999
    Richland, Washington 99352

    BCS Richland, Inc.
    P.O. Box 300
    Richland, Washington 99352

    Hanford Environmental Health Foundation
    P.O. Box 100
    Richland, Washington 99352

    J.A. Jones Construction Company
    801 First Street
    Richland, Washington 99352

    United Nuclear Industries, Inc.
    P.O. Box 490
    Richland, Washington 99352

    Vitro Engineering Corporation
    P.O. Box 296
    Richland, Washington 99352

    Westinghouse Hanford Company
    P.O. Box 1970
    Richland, Washington 99352

3. 700 Area — RL
Richland Federal Building
825 Jadwin Avenue
Richland, Washington

Responsible
Field Office

Washington (Continued)

3. 700 Area (Continued)

Principal Contractors:
Rockwell International
Rockwell Hanford Operations

Battelle-Pacific Northwest Laboratory

BCS Richland, Inc.

Hanford Environmental Health Foundation

United Nuclear Industries, Inc.

Vitro Engineering Corporation

Westinghouse Hanford Company

4. 703 Building
Knight Street RL
Richland, Washington

Principal Contractors:
Rockwell International
Rockwell Hanford Operations

Battelle-Pacific Northwest Laboratory

BCS Richland, Inc.

Hanford Environmental Health Foundation

5. a. 712 Building
Northgate Drive RL
Richland, Washington

b. 1100 Area
Stevens Drive RL
Richland, Washington

c. Columbia Bank Building
1100 Jadwin Avenue RL
Richland, Washington

Responsible Field Office

Washington (continued)

d. Tannadore Building
1155 Jadwin Avenue
Richland, Washington
RL

e. Richland Sky Park
Terminal Building
Richland Airport
Richland, Washington
RL

Principal Contractor:
Rockwell International
Rockwell Hanford Operations
P.O. Box 250
Richland, Washington 99352

6. 747 Building
Knight Street
Richland, Washington
RL

Principal Contractors:
Hanford Environmental Health Foundation

Battlle-Pacific Northwest Laboratory

7. a. 748 Building
Swift Street
Richland, Washington
RL

b. Medical-Dental Building
Swift Street
Richland, Washington
RL

Principal Contractor:
Hanford Environmental Health Foundation
P.O. Box 100
Richland, Washington 99352

8. 3000 Area
First Street
Richland, Washington
RL

Principal Contractor:
J. A. Jones Construction Company
801 First Street
Richland, Washington 99352

Washington (continued)

		Responsible Field Office
9. a.	Port of Benton Building 2592 George Washington Way Richland, Washington	RL
b.	Hanford Square 1 Building 3080 George Washington Way Richland, Washington	RL
c.	Group V Building 3200 George Washington Way Richland, Washington	RL
d.	GESA Building 723 Parkway Richland, Washington	RL
e.	Robert Young Building 1933 Jadwin Avenue Richland, Washington	RL
f.	Robert Young Building 1955 Jadwin Avenue Richland, Washington	RL
g.	Hanford Square 4 Building 3060 George Washington Way Richland, Washington	RL
h.	Sigma III Building 316 George Washington Way Richland, Washington	RL
i.	Sigma IV Building 3170 George Washington Way Richland, Washington	RL
	Principal Contractor: Battelle-Pacific Northwest Laboratory P.O. Box 999 Richland, Washington 99352	
10.	Robert Young Building 1933 Jadwin Avenue Richland, Washington	RL

Responsible
Field Office

Washington (continued)

Principal Contractor:
Vitro Engineering Corporation
P.O. Box 296
Richland, Washington 99352

11. a. Jadwin Building — RL
1135 Jadwin Avenue
Richland, Washington

b. 3190 Building — RL
3190 George Washington Way
Richland, Washington

c. 3180 Building — RL
3180 George Washington Way
Richland, Washington

Principal Contractor:
Westinghouse Hanford Company
P.O. Box 1970
Richland, Washington 99352

Puerto Rico

1. a. Nuclear Research and Training Center — OR
Rio Piedras, Puerto Rico

b. Nuclear Research and Training Center — OR
Mayaguez, Puerto Rico

c. El Verde Terrestrial Ecology Station — OR
Loquillo National Forest
Puerto Rico

Abbreviations:
AL - Albuquerque
CH - Chicago
OR - Oak Ridge
RL - Richland
SAN - San Francisco
NV - Nevada
GJ - Grand Junction
SNR - Schenectady Naval Reactor
ID - Idaho
PNR - Pittsburgh Naval Reactor
HQ - Headquarters